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THE COLLEGE OF AERONAUTICS

DEPARTMENT OF AIRCRAFT DESIGN

Structural testing of wooden aircraft

S U M M A R Y

For some years now the structural integrity of wooden aircraft of timber and glued plywood torsion box construction has been a matter of concern to the Air Registration Board since it is impossible to assess, by inspection, the strength of an apparently sound glued joint. A programme of testing two representative specimens of two types of aircraft was therefore agreed by the Ministry of Aviation and carried out by the College in conjunction with the Air Registration Board.

This report deals with the factual aspects of these tests which were conducted during the period December 1963/February 1964 in the Structural Testing Laboratory of the Department of Aircraft Design.

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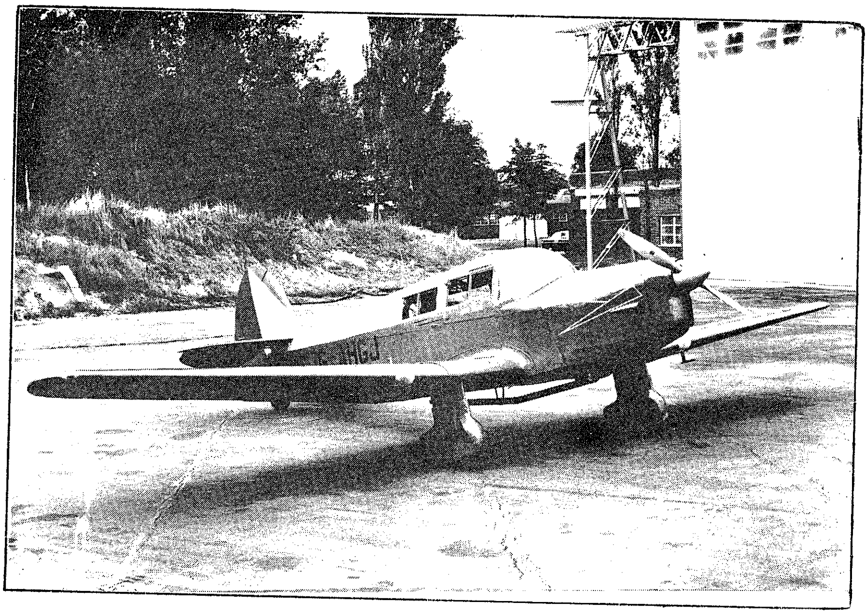
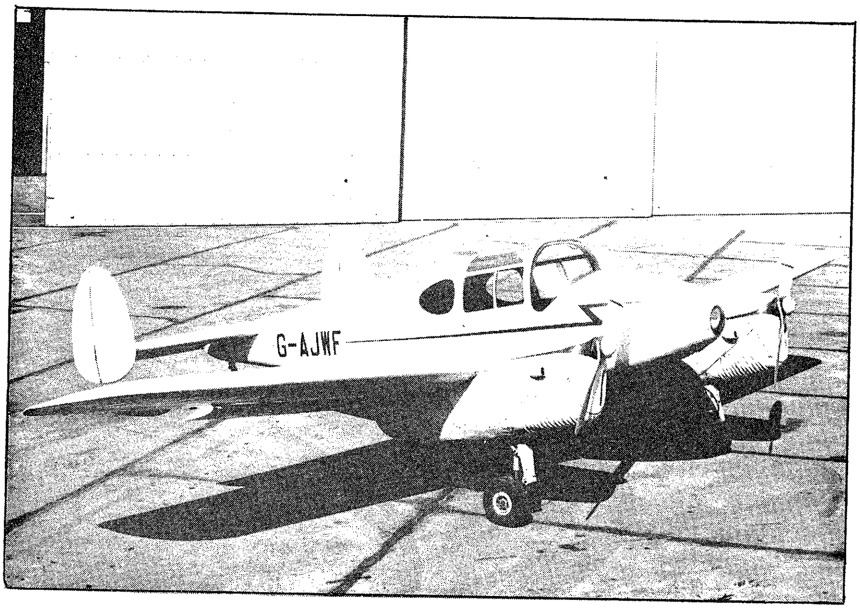


PERCIVAL PROCTOR T.9/41 MK V



MILES GEMINI M.65. MK IA

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1.0 Introduction

For some years now the structural integrity of certain types of wooden aircraft has been a matter of concern, partly because many still in use are now fifteen or more years old, and partly because of the difficulty in making an adequate inspection of the structure, without rendering the subsequent repairs prohibitively expensive. A further difficulty is the assessment of the strength of a glued joint, even where it can be readily inspected.

This concern has resulted in restrictions being imposed on the operation of certain types of wooden aircraft by the A.R.B. and the D.C.A. of Australia and, more recently, by the aviation authorities of other countries. The A.R.B. considered that the evidence it had in its possession justified the actions taken but was concerned that perhaps the problem was more serious; it was quite possible that wooden aircraft in apparently sound condition would have lost a significant amount of their original design strength. Accordingly it was decided to test to destruction a number of aircraft mainplanes and tailplanes. The aircraft were chosen with regard to:-

1. their age,
2. the type of construction, e.g. sealed box spars,
3. the types of glue used in manufacture,
4. the number still on the U.K. register.

A contract was subsequently placed with the College of Aeronautics, to purchase, in collaboration with the A.R.B., two Miles Gemini M.65 aircraft, and two Percival Proctor Mks. IV or V aircraft for destructive tests. The aircraft were to be apparently sound structurally, with every likelihood of being re-certificated without trouble for several years.

The aims of testing were to see if, despite apparently sound structural condition, the aircraft were in fact dangerously low in strength, necessitating more drastic action by the A.R.B.,[1,2] and to see if some datum could be found whereby a simple visual check would with some certainty, assess the internal structural integrity.

2.0 Test specimens

Aircraft details:-

Type	Registration	Constructors Number	Year of Manufacture	Total No. of Hours Flown
Percival Proctor T.9/41 Mk. V	G-AHGJ G-AHBA	Ae.41 Ae.17	1946 1946	696 1273
Miles Gemini M.65 Mk. IA	G-AJWC G-AJWF	6295 6291	1947 1947	1149 549
Miles Gemini M.65 Mk.VII	G-AMGF	WAL/C.1003	1951	1321

The first four aircraft noted above were purchased on the open market by the College, in conjunction with the A.R.B. and had been based throughout their lives in the United Kingdom. The last aircraft, the Mk.VII Gemini, was donated by Shell Aviation Ltd., and although it spent most of its life in European conditions, had made many trips abroad in tropical and semi-tropical climates. Also, although the aircraft was constructed in 1951, parts were manufactured much earlier (inspection stamps on wing components were dated 1947).

Aircraft conditions as described briefly in the introduction were fulfilled and all machines with the exception of the Shell Gemini were either flown in to Cranfield by College pilots or flight tested soon after arrival, prior to grounding. The Shell aircraft was dismantled at London Airport and components only were received by the College, however, the port wing was found on receipt, to be damaged such that it could not be used as a representative specimen hence the tests were carried out on starboard wing and tailplane only. Appendices 1 and 2 refer to structural condition of the purchased aircraft whilst Appendix 3 certifies general airworthiness on acceptance.

Figures 14 to 18 indicate minor structural defects on the actual test components, discovered during preparation.

3.0 Loading information

The proposed test loadings were submitted to A.R.B. for agreement prior to commencement of the test programme. Approval is recorded in Appendix 4 and the comparative tables etc. of test loads against design loads are included in Appendix 5. These tables are based on type record information for the Gemini, a test report by Percival Aircraft Ltd., on Proctor wings and information supplied by Hunting Aircraft Ltd. (B.A.C.) for Proctor tailplane load distribution.

Figures are included in the tables which give comparative torque conditions on the wings and tailplanes of both aircraft types using this loading system. The margin of torque application is consistently slightly greater, in the case of the Proctor, than the worst type record condition whilst the Gemini loading, although not producing consistently greater torques, does in fact do so locally as indicated in the appropriate figure. It was felt that this should be adequate to highlight any joint failures assuming a uniform glue deterioration.

Maximum loads were obtained using recommended design factors based on B.C.A.R. or a forerunner of this document. The quoted factors are 'proof' and 'ultimate'; 'proof' being equal to the 'limit load' which is also equal to the 'maximum design load'. 'Ultimate' or fully factored load (F.F.L.) equalling the proof load multiplied by a factor of safety, in this case 1.5.

The minimum reserve factor (R.F.) for each test item, based on ultimate calculated loads and extracted from the relevant test report or type record, is as follows:-

Aircraft	Wing	Tailplane
Proctor	RF = 1.4*	RF = 1.05
Gemini	RF = 1.0	RF = 1.0

An RF = 1.0 indicates that the considered item has a calculated maximum strength equal to the ultimate strength. (It should be noted that 'ultimate' strengths are in fact 'minimum ultimate' in view of the high structural scatter factor applicable to timber generally. This would no doubt help to explain the high ultimate loads subsequently supported by Gemini wings and the tailplanes of both types when compared with minimum reserve factors of 1.00 and 1.05 quoted in the type records). Apart from the 'Proctor' wing*, which was an actual test, all above RF's are based on type record information.

Loading cases:-

Aircraft	Component	Case	Source
Proctor	Wing	C.P. For'd	Test Report 529/4 P.28/39 Based on BCAR 1949
	Tailplane	A.P.1208 Leaflet B.3 Para. 9	Type Record and Letter Ref. ENBB/BAI of 14.1.64
Gemini	Wing	B (A.R.B. Handbook D.3)	Type Record } BCAR 1946
	Tailplane	3 (A.R.B. Handbook D.4)	Type Record } BCAR 1946

The above cases are considered to be the most critical which can be applied. They are extracted from the sources indicated and a direct comparison with actual failing loads under test is therefore possible.

4.0 Description of test equipment and preparation of specimens

4.1 Wings

A simple loading rig was devised to reproduce actual air loads. As the College test rigs were not suitable for testing complete wings, i.e. tip to tip, it was agreed that outer wings only would be tested. In the case of the Proctors the wings outboard of the wing joint (from the folding position) were tested, but the Gemini wings are of one piece construction, tip to tip, hence the spars were cut at the centre line of the aircraft to give two half wings. By testing outer wings only, the existing cruciform test rig in the College's Structural Testing Laboratory was utilised with the minimum of alteration.

The Proctor mainplanes were attached to a face plate on the cruciform rig via special brackets which picked up the existing outer wing attachment brackets. The Gemini wing attachment was not so simple as the Proctor since the stub ends of the spars had to be reinforced by inserting blocks between webs and booms and plating both webs externally from the inboard end of the spars, outboard, to pick up the fuselage attachment points. Mild steel angles were used for the attachment of the reinforced spar stub end to the rig. It was, of course, realised that this local reinforcing inhibited testing of the centre section of the Gemini wing, also that the applied loading did not simulate local conditions on all specimens especially at the rig rib/skin connections, but time and test rig availability did not permit the extra complication of additional pick-ups or more sophisticated methods.

Attachment to the rig resulted in the wings being inverted. That is, with the under-surface uppermost, such that flight loads could be reproduced by pulling downwards. Rig weight was therefore additive and maximum loads adjusted accordingly.

Load was applied at twelve positions on each wing, six on each spar, the positions being arranged to give reasonably accurate shear, bending and torque conditions. Each loading point consisted of a 'tee' section on one surface of the wing and a plate on the other surface of similar size, joined by four screwed rods, two on each side of the spar section, suitable packing being inserted under the 'tee' and plate to match the wing contours. The Gemini wings have a plywood skin completely covering the surface, and this had to be perforated at each pickup position for tie rod access. In the Proctor wings, however, only the leading edge is skinned with ply the remainder being fabric covered. The latter was stripped from all wings subsequent to the first to ease pickup attachment and to observe test breakage more easily.

A 'whiffle tree' arrangement (See Fig. 1) was used to distribute load along each spar, the two spar loading systems being connected by a cross beam, such that load could be applied to the whole system at one point, via a dynamometer by hydraulic jacks. The Proctor wing loading is straightforward since all loads act in the same direction but the Gemini wing has load reversal at the engine position. To obtain this load reversal, a cable was run from the whiffle tree, over pulleys mounted above the wing on a fabricated structure, and down to 'tee' fittings on the opposite side.

For the first test of each type, Vernier tape gauges were used on both spars to measure wing deflections, and dial gauges at the root to check rig movement. In subsequent tests of the same types only the structural failures and the loads at which they occurred were noted. Figures 2 and 3 show the wing rigs before loading.

4.2 Tailplanes

Both types of tailplane were tested as complete units. The tailplanes were mounted via existing brackets and attachments to a small platform outrigged from the cruciform rig face.

The Proctor tailplane has two spars, each with a separate loading system. The front spar was loaded downwards at six positions via a lever system, dynamometer and jack similar to the wing tests, but the rear spar, which required a small upward load was loaded via two lever, cable and pulley systems and shot bags. Pickups on the tailplane were similar to the wing fittings.

The Gemini tailplane has only one spar and to achieve the correct loadings, contour boards had to be used with single load application points, in conjunction with one additional pickup outrigged off each of the two fin attachment brackets. Eight loading points were used.

As for the wings, vernier tape and dial gauges were utilised for the first test of each type only.

Figures 4 and 5 show the tailplane rigs before loading.

5.0 Test procedure

Representatives of A.R.B., A.I.B., the Forest Products Research Laboratory, the Timer Research and Development Association and B.A.C. Ltd., Luton Division, (Percivals) or Beagle Aircraft Ltd. (Miles) were invited to attend each test, the latter two for the particular make of aircraft with which they were concerned.

Each specimen was lightly loaded and released several times to settle the rig. Loading then proceeded in suitable increments until complete failure, noting deflections where applicable, and partial failures with corresponding loads.

6.0 Results

The following is a brief record of each test, with all failures noted against percentage of the fully factored load, (ultimate) and also, where relevant, the corresponding acceleration magnitude 'g'. These are summarised in table form at the end of section 7.

Test No. 1 Proctor V. Port Wing

Registration G-AHGJ. Date 6th December, 1963

A preliminary test was carried out on this first specimen only, to

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obviate any errors in procedure and to settle the rig and loading attachments. A total of 2,400 lbs. was applied making a gross test load of 3210 lbs. representing 64 per cent of the fully factored load (F.F.L.) or 3.4g applied.

All gauges, tape and dial, were noted for load increments of 400 lbs. up to 2810 lbs., and 200 lbs. to 3210 lbs. and in similar steps back to zero. The test indicated no snags in the system, the rig assembly settled somewhat, but not excessively.

Test No. 1 proper

As in the preliminary test, the load was applied initially in 400 lb. increments, to 72 per cent F.F.L. (3.8g). Five further increments of 200 lbs. were then applied, each load being held a few minutes before increasing, and after approximately 2 minutes at 92 per cent F.F.L. (4.8g) there was an unidentified minor failure in the root area, followed by complete failure of the front spar wooden boom at the fitting attachment.

Test No. 2 Proctor V. Starboard wing.

Registration G-AHGJ. Date 6th December, 1963

This was the other outer wing of the aircraft tested as described above. Loading was identical and at 52 per cent F.F.L. (2.7g) a minor failure occurred in the region of the root. It was thought that the root rib glueing had parted but this was not established, and at 92 per cent F.F.L., (4.8g) as in the port wing test, the front spar failed at the root attachment.

Test No. 3 Gemini Mk. IA. Port Wing.

Registration G-AJWC. Date 13th December, 1963

After settling the rig, loading proceeded in 400 lb. increments up to 48 per cent F.F.L. (2.5g) thence in 200 lb.* steps to 84 per cent F.F.L. (4.4g) when the lower plywood skin split open from the corner of the inboard inspection panel forward to the front spar. At 87 per cent F.F.L. (4.6g) the same split extended aft to the rear spar, leaving a complete gap in the skin between spars. A similar split appeared at the second inspection panel, inboard of the aileron root at 89 per cent F.F.L. (4.7g). From this point the wing was loaded in 100 lb. increments, allowing each load a few moments 'settling' time, until both spars failed completely at 106 per cent F.F.L. (5.6g).

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* Due to a certain amount of sticking in the jacks it was not always possible to attain the required load increments, especially when the total applied load was high.

Test No. 4   Gemini Mk.IA.   Starboard wing.

Registration G-AJWC.   Date 16th December, 1963.

Load was applied to 53 per cent F.F.L. (2.8g) in 400 lb. increments, and then in 200 lb. steps to 71 per cent F.F.L. (3.7g) when, as in Test No. 3 the under skin split open from an inspection panel corner, and the indicated load dropped 100 lb. Loading then proceeded in 200 lb. increments (average) until total spar failure at 138 per cent F.F.L. (7.2g).

Test No. 5   Gemini Mk.IA.   Starboard wing.

Registration G-AJWF.   Date 17th December, 1963.

The specimen was loaded as in the previous tests, and, as before, the under skin failed initially at the inboard inspection panel, this time at 43 per cent F.F.L. (2.3g) the plywood breaking completely through for a length of several inches. The crack opened and lengthened further at 48 per cent F.F.L. (2.5g). No other partial failures occurred, and the spars finally failed at 140 per cent F.F.L. (7.35g). This was the highest recorded breaking load.

Test No. 6   Gemini Mk.IA.   Port wing.

Registration G-AJWF.   Date 18th December, 1963

A typical test, the under wing skin split open initially from the inboard inspection panel, at 35 per cent F.F.L. (1.8g) to the front spar, and then backward to the rear spar at 88 per cent F.F.L. (4.7g). The ply skin was then completely broken between spars at this position. The latter failure caused the applied load to drop to 86 per cent F.F.L. (4.5g). Loading continued and at 126 per cent F.F.L. (6.7g) the skin failed at the outboard inspection panel position, failure being a typical tension breakage, (for this wing type) and the spars finally failed completely at 137 per cent F.F.L. (7.2g).

Test No. 7   Proctor V.   Port wing.

Registration G-AHBA.   Date 3rd January, 1964.

The wing was loaded as in previous tests and at 57 per cent F.F.L. (3g) and 81 per cent F.F.L. (4.3g) small internal cracks occurred; it was not established what part of the structure had failed, and at 94 per cent F.F.L. (4.9g) the front spar boom failed in bearing at the attachment bolt position, the load dropping to 84 per cent F.F.L. (4.4g) this being a similar failure to tests Nos. 1 and 2. Since the load did not fall off appreciably, due to the rear spar remaining sound, loading proceeded again until this was broken at 93 per cent F.F.L., this was done purely for interest and had, obviously, no bearing on the overall test.

Test No. 8. Proctor V. Starboard wing

Registration G-AHBA. Date 3rd January, 1964.

The specimen broke at the front spar root position as in previous tests. Failure of the front spar was at 88 per cent F.F.L. (4.6g) and the test load fell off to 40 per cent F.F.L., this being carried by the rear spar. As in the previous test (No. 7) loading was continued, and the rear spar failed at 56 per cent F.F.L. No minor failures occurred during the test cycle.

Test No. 9. Gemini Mk. IA. Tailplane

Registration G-AJWF. Date 10th January, 1964.

Load was applied in 50 lb. increments, throughout the entire range. There were internal creaks at stages up to 138 per cent F.F.L. when there was a minor failure in the centre section area, and the load dropped to 134 per cent F.F.L. This load was held for several minutes, after which time another failure occurred internally and the load dropped to 132 per cent F.F.L. Loading continued and at 150 per cent F.F.L. the port tip rib/skin connection cracked* allowing the total load to drop slightly. At 181 per cent F.F.L. the port tip front spar rig collapsed. The high loads applied caused both the skin/rib glue separation due to the offsets, and the final failure of the rig, and are not relevant to the test.

Test No. 10. Gemini Mk.IA Tailplane

Registration G-AJWC. Date 10th January, 1964.

Due to the high order of maximum load attained during Test No. 9 it was not considered necessary to alter the rig at this time. The test therefore proceeded as before, and at 95 per cent F.F.L. there was a failure in the upper centre section, causing the load to drop slightly. This load was held for several minutes, but no further failure occurred, and the skin parted from the root rib at the leading edge on the starboard side at 115 per cent F.F.L. The load fell off to 83 per cent F.F.L. and the test was discontinued at this point. This was the only time a glue failure terminated testing.

Test No. 11 and 12 Proctor V. Tailplane

Registration G-AHGJ and G-AHBA. Date 21st January, 1964.

Both tailplanes were loaded to 168 per cent F.F.L. in 50 lb. steps,

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* For ease of rig attachment, the forward pickup of the loading arm at each tip position was connected to the fin forward mounting bracket, this was merely a spruce block, with bushed hole for fin attachment, glued and bradded to the outboard rib, with very little backing, and obviously was not intended to carry the order of loads applied by the test, i.e. in excess of 150 per cent of calculated load. However, initially, this order of loading was not visualised and the simplified rig arrangement philosophy was justified at that time.

as for the Gemini tailplane test. At this load, since the rig was showing marked signs of distortion, and no failure of any kind was evident, the tests were abandoned. The second specimen, (G-AHBA) was subjected to this maximum load for 35 minutes, and still remained intact.

Test No. 13. Gemini Mk.VII. Starboard wing.

(Extra test) Registration G-AMGF. Date 5th February, 1964.

This was the first of 2 extra test specimens to the original contract commitment. The test procedure was varied slightly in this case in that the loading was continuous between zero and each failure.

Unlike the Mk.IA types, this wing contained a tank bay in the leading edge. The first failure occurred at this position at 58 per cent F.F.L. (3g) and was probably the tank attachment structure parting. At 68 per cent F.F.L.(3.6g) cracks were heard in the region of the outboard inspection panel, and, after a pause, the under skin split from the hinge end on the intermediate inspection panel running forward to the leading edge with the load dropping slightly. Loading proceeded and at 80 per cent F.F.L. (4g) the same crack ran aft to the trailing edge. At 83 per cent F.F.L. (4.4g) the skin at the outboard inspection panel split right across the chord, and at 96 per cent F.F.L. (5g) the skin split at the inboard inspection panel. A failure occurred internally in the wing at 102 per cent F.F.L. (5.4g) this was not identified, and at 107 per cent F.F.L. (5.6g) the inboard inspection panel split increased in size and ran aft over the rear spar. At 111 per cent F.F.L. (5.8g) the skin lifted off the spar at the outboard reverse load position, and the load dropped to 110 per cent F.F.L. There was a complete failure of the front spar at 130 per cent F.F.L. (6.8g).

Test No. 14. Gemini Mk.VII. Tailplane.

(Extra test) Registration G-AMGF. Date 5th February, 1964.

Loading technique was as before for this specimen, there were unidentified internal cracks at 76 per cent F.F.L. and 90 per cent F.F.L. The starboard tip rib buckled and cracked at 123 per cent F.F.L. and there was a further crack at 134 per cent F.F.L. At 146 per cent F.F.L. the skin split on the upper surface of the centre section, and the test was discontinued.

6.1 Discussion of results

The aims of the testing as outlined in Section 1.0 were:-

a) To ascertain whether the aircraft were dangerously low in strength.

b) To try to establish a visual inspection datum.

The results indicated that the aircraft in general were not seriously lacking in ultimate strength, compared with the original type record figures.

The fact that all Proctor wings failed consistently at approximately 90 per cent of their estimated strength is, however, worthy of note, especially as a similar test carried out by Percival Aircraft Ltd., in 1950, gave a test result of 140 per cent F.F.L. as a minimum figure for two new outer wing sections. This indicates an apparent strength reduction of some 35 per cent for the wings tested by the College, the type and position of the failure being almost identical.

Although Gemini wing failures were with one exception, consistently high in ultimate strength (the lowest figure obtained still being in excess of 100 per cent F.F.L.), the tension failures at inspection holes on the under wing skin did occur at comparatively low load factors (1.8g in the case of G-AJWF).

All tailplanes, with the exception of one Gemini glue failure, also were consistently high in ultimate strength.

No basis was established during or subsequent to the testing, whereby a visual inspection of an apparently sound aircraft would indicate a serious reduction in overall strength.

7.0 Conclusions

7.1 General

All failures were, with the exception of one Gemini tailplane, failure of the timber part of the load carrying structure. There were apparently no failures directly or indirectly attributable to lack of strength in the glued joints. Throughout this section, 'failure' indicates complete collapse of the test item and consequent release of the test load.

The skin to root rib glue joint failed on one of the Gemini tailplanes.

Proctor

7.2 Wings

All Proctor wing spar failures occurred at the root joint connection, and were bearing failures in the front spar booms. Ultimate strength of the wings was within the range 88 per cent to 94 per cent F.F.L.

It was noted that the type of failure on all Proctor wings was similar to that experienced by Percival Aircraft Ltd., on the reinforced full wing specimen, tested in 1950, and recorded in their report No. 529/4 - P28/39. The only difference being that, in the 'Percival' test, both spars failed simultaneously, whereas in the College test only the front spar failed initially. The test of new wing specimens produced a minimum ultimate strength of 140 per cent F.F.L., showing an apparent strength reduction of 35 per cent over 14 years operation. The original calculated minimum RF for the wings was 1.02 (102 per cent F.F.L.).

7.3 Tailplanes

Both tailplanes withstood loads of 168 per cent F.F.L. without failure of any kind. The original minimum calculated RF from the type record, was 1.05 or 105 per cent F.F.L.

Gemini

7.4 Wings

All Gemini wing skin cracks referred to in table 1 (with the exception of the leading edge of G-AMGF - test number 14) occurred at the corner of the handhole hinge cut-out and were propagated from that point at relatively low percentage fully factored load. The cracks were, without exception, of considerable size, i.e. a minimum length split in the plywood of approximately 6", the plywood being completely ruptured over the length of the split, and easily recognisable. The original RF (minimum) for the wings was 1.0 (100 per cent F.F.L.).

7.5 Tailplanes

In the case of one Gemini tailplane (test number 10), the applied load at skin joint failure was 115 per cent of the fully factored load. This was the only glue failure of the series, and is a significantly lower figure than those obtained for the other two tailplanes, which exceeded 181 per cent and 146 per cent F.F.L. respectively. The type record calculated factor is 1.0 minimum, i.e. 100 per cent F.F.L.

Note: Minor defects found during preparation of the specimens (see figs. 14 to 18) appeared to have no bearing on the final failing loads.

Actual results and failure sequences are summarised in the following tables:-

TABLE 1 Summary of results

Test Number	Aircraft Type	Registration	Component	Design Load (Fully Factored) (lbs)	Max. load Supported	Max. Load Supported as Percentage of Fully Factored Design Load	Acceleration Magnitude 'g'
1	Proctor Mk. V	G-AHGJ	Port wing	4995	4610	92	4.8
2			St'b'd wing	4995	4610	92	4.8
11			Tailplane	1316	2216(MAX)	168 (No failure)	-
7	Proctor Mk. V	G-AHBA	Port wing	4995	4710	94	4.9
8			St'b'd wing	4995	4410	88	4.6
12			Tailplane	1316	2216(MAX)	168 (No failure)	-
3	Gemini Mk. IA	G-AJWC	Port wing	7886	8380	106	5.6
4			St'b'd wing	7886	10880	138	7.2
10			Tailplane	1278	1464	115	-
6	Gemini Mk. IA	G-AJWF	Port wing	7886	10780	137	7.2
5			St'b'd wing	7886	11080	140	7.35
9			Tailplane	1278	2314	181 (Rig failure)	-
13	Gemini Mk. VII	G-AMGF	St'b'd wing	7886	10280	130	6.8
14			Tailplane	1278	1864(MAX)	146 (No total failure)	-

TABLE 2 Summary of failure sequences

AIRCRAFT TYPE	REG.	PORT WING		STARBOARD WING		TAILPLANE	
		NATURE	F.F.L. %	NATURE	F.F.L. %	NATURE	F.F.L. %
Proctor T9/41 Mk. V	G-AHGJ	Front spar failure at root	92	Unidentified crack near root Front spar failure at root	52 92	No failure	168
	G-AHBA	Small internal crack Small internal crack Front spar failure at root	57 81 94	Front spar failure at root	88	No failure	168
Gemini M65. Mk. IA	G-AJWC	Skin crack (inbd) Skin crack (inbd) Skin crack (mid) Total failure(spar)	84 87 89 106	Skin crack (outbd) Total failure (spar)	71 138	Skin crack (upper c/s) Glue and skin failure (Stbd L.E. U/side R. rib)	95 115
	G-AJWF	Skin crack (inbd) Extending across chord Skin crack (outbd) Total failure(spar)	35 88 126 137	Skin crack (inbd) Skin crack (outbd) Total failure(spar)	43 48 140	Unidentified internal failure at centre section Rig failure	138 181
Gemini M.65 Mk. VII (Shell)	G-AMGF	------		L.E. skin crack Skin crack (mid) Skin crack (mid) Skin crack (outbd) Skin crack (inbd) Internal crack (unidentified) Skin crack (inbd) F/spar outbd engine attachment skin lifted Total failure (spar)	58 68 80 83 96 102 107 111 130	Internal crack (unidentified) Internal crack (unidentified) Tip rib crack Tip rib crack Skin crack(upper c/section outbd)	76 90 123 134 146

Acknowledgments

The assistance given by Mr. E.N.B. Bentley of Hunting Aircraft Ltd. and Mr. Niedermeyer of Beagle Aircraft Ltd., in arriving at the test loadings was invaluable in the compilation of this report. Thanks are also due to the Forest Products Research Laboratory of the Department of Scientific and Industrial Research for carrying out a detail assessment of glued joints in the broken specimens (appendix 6) and to Shell Aviation Ltd., for the donation of wings and tailplane of their Gemini aircraft for test purposes.

References

1. Note No. 50 A.R.B. notice to Licensed Aircraft Engineers.

2. Note No. 67 A.R.B. notice to Licensed Aircraft Engineers.

Attention is also drawn to the following:-

Glue Deterioration in Wooden Aircraft by P.S. Langford and K. O'Brien. Department of Civil Aviation, Australia.

APPENDIX 1

Aircraft Approval (Copy of letter, Ref. DEF/514, from the Air Registration Board).

G-AJWC.	Miles M.65 Gemini IA
G-AJWF.	Miles M.65 Gemini IA
G-AHBA.	Percival Proctor V
G-AHGJ.	Percival Proctor V

The four above-mentioned aircraft have been inspected by the undersigned and their condition is considered to be satisfactory for the physical test programme to be carried out by the College of Aeronautics at Cranfield, Bedfordshire.

H. SMITH

J. TEMPLETON

For Secretary, Air Registration Board.

APPENDIX 2

Inspection Approval (Copy of internal memo, Ref. CA1/2/DVP/JMR, from the Chief Aircraft Inspector).

The undermentioned aircraft have been inspected by the writer prior to their acceptance as suitable test specimens.

In all instances, these machines were found to be good examples of the type, airworthy, and possessing a current Certificate of Airworthiness.

Unfortunately, in one case, more maintenance information in the log books since last renewal would have been useful, but I am satisfied that no major structural repairs have been undertaken on any of these aircraft.

G-AHBA.	Percival Proctor V
G-AHGJ.	Percival Proctor V
G-AJWF.	Miles M.65 Gemini IA
G-AJWC.	Miles M.65 Gemini IA

D.V. PRICE
Chief Aircraft Inspector

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APPENDIX 3

Airworthiness Report (Copy of internal memo. Ref. DF/AIR/230, from College test pilot)

Gemini aircraft, Reg. Nos. G-AJWF and G-AJWC together with Proctor aircraft, Reg. Nos. G-AHGJ and G-AHBA were flown to check airworthiness and handling characteristics. All aircraft were found to be completely airworthy and, from a handling point of view, good examples of their type. The controls, in all cases, were well harmonized and there appeared to be no reason why the aircraft should not meet the Air Registration Board Air test requirements.

Sq'dn/L'dr. I.A. ROBERTSON
Deputy Head, Department of Flight.

APPENDIX 4

Test Loading Approval (Copy of letter, Ref. DEF/514, from the Air Registration Board).

Thank you for your letter of 11th October 1963, enclosing a copy of your proposed test loadings. I would confirm that the Board is in agreement with the proposals outlined.

I shall be most interested to hear further from you in due course.

A.P. KENNEDY

APPENDIX 5: TABLE 1

Type: Percival Proctor V. Wing test.

Table of B.M's and shear forces

Case taken for test:

CP fw'd, fully factored max. normal acceleration coefficient of 5.25 and an A.U.W. of 3,500 lb. (Percival Test Report 529/4 - P28/39)

Rib	Dist. from Outer Wing Joint. (ins)	B.M. (lb. in.)		Shear (lb.)	
		Front spar	Rear spar	Front spar	Rear spar
C	0	309,030	162,000	3,560	1,821
D	16.43	250,540	132,080	3,560	1,821
E	32.00	202,680	108,500	3,074	1,514
F	47.40	157,370	85,450	2,942	1,497
G	62.00	120,920	65,800	2,497	1,346
H	76.90	87,560	47,340	2,239	1,239
K	91.00	61,300	32,790	1,862	1,032
L	104.66	40,650	21,370	1,512	836
M	118.00	24,990	12,640	1,174	654
N	130.83	13,620	6,530	886	476
O	143.00	6,210	2,770	609	309
P	154.27	2,050	860	369	170
Q	165.00	0	0	191	80

C of A Test Loading

Rib	Dist. from Outer Wing Joint (ins)	B.M. (lb. in.)		Shear (lb.)	
		Front spar	Rear spar	Front spar	Rear spar
C	0	309,030	162,000	3,323	1,672
E	32.00	202,680	108,500	3,323	1,672
G	62.00	120,920	65,800	2,725	1,423
K	91.00	61.300	32,790	2,056	1,138
M	118.00	24,990	12,640	1,349	746
O	143.00	6,210	2,770	751	395
Q	165.00	0	0	282	126

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APPENDIX 5: TABLE 2

Type: Percival Proctor V Tailplane test.

Table of B.M.s. and shear forces

Case taken for test: A.U.W. 3300 lb. - C.P. forward.

Front spar: As in Percival Proctor Type Record.

Rear spar: Letter from Mr. E.N.B. Bentley, Chief Airworthiness Engineer, British Aircraft Corporation Ltd., Luton Division (REF. ENBB/BAI of 14th January, 1964).

Dist. from ℄ of A/C (ins)	B.M. (lb. in.)		Shear (lb.)	
	Front spar	Rear spar	Front spar	Rear spar
0	17,700	-3,120	-30	-108
5.8	17,900	-	-	-
8.2	16,000	-2,300	720	-92
17.8	10,000	-1,520	610	-84
27.1	5,600	-810	470	-44
36.4	2,600	-506	330	-37
45.7	700	-220	210	-29
54.7	300	-14	80	-11

C of A Test Loading

Dist. from ℄ of A/C (ins)	B.M. (lb. in.)		Shear (lb.)	
	Front spar	Rear spar	Front spar	Rear spar
0	-	-3,501	-	-100
5.8	17,900	-	658	-
17.8	10,000	-1,721	658	-100
36.4	2,600	-586	398	-61
54.7	-	-	142	-32

APPENDIX 5: TABLE 3

Type: Miles Gemini IA and VII. Wing Test.

Table of B.M.'s and shear forces

Case taken for test:

'Case B' in Miles Gemini Type Record.

Dist. from ℄ of A/C (ins)	B.M. (lb. in.)		Dist. from ℄ of A/C (ins)	Shear (lb)	
	Front spar	Rear spar		Front spar	Rear spar
0	245,000	242,000	0	-	-
22	245,000	242,000	22	130	3240
40	246,000	186,000	40	130	3150
53	236,000	148,000	49.95	100/1760	-
60	227,000	129,000	54.7	-	2950/2240
67	215,000	113,000	60	1500	2460
80	187,000	87,000	65.3	-	2700/1980
100	140,000	56,000	70.05	1280/3000	-
120	91,000	34,000	80	2800	1700
133	66,000	24,000	98	2430	1350
140	53,000	20,000	117	2070	1000
160	30,000	10,000	130	1800	750
180	15,000	5,000	150	1300	500
200	5,000	1,000	159	1100	400
217	0	0	180	610	200
			200	250	60
			217	0	0

C of A Test Loading

Dist. from ℄ of A/C (ins)	Front Spar		Dist. from ℄ of A/C (ins)	Rear Spar	
	B.M.(lb.in)	Shear (lb)		B.M.(lb.in.)	Shear (lb)
22	249,500	214	22	239,000	3000
50	243,500	214	55	140,000	3000
70	214,500	1450	65	115,000	2500
110	112,500	2550	100	59,000	1600
145	46,000	1900	130	26,000	1100
170	21,000	1000	160	10,000	533
205	-	600	190	-	333

APPENDIX 5: TABLE 4

Type: Miles Gemini IA and VII. Tail plane test.

Table of B.M.'s and shear forces

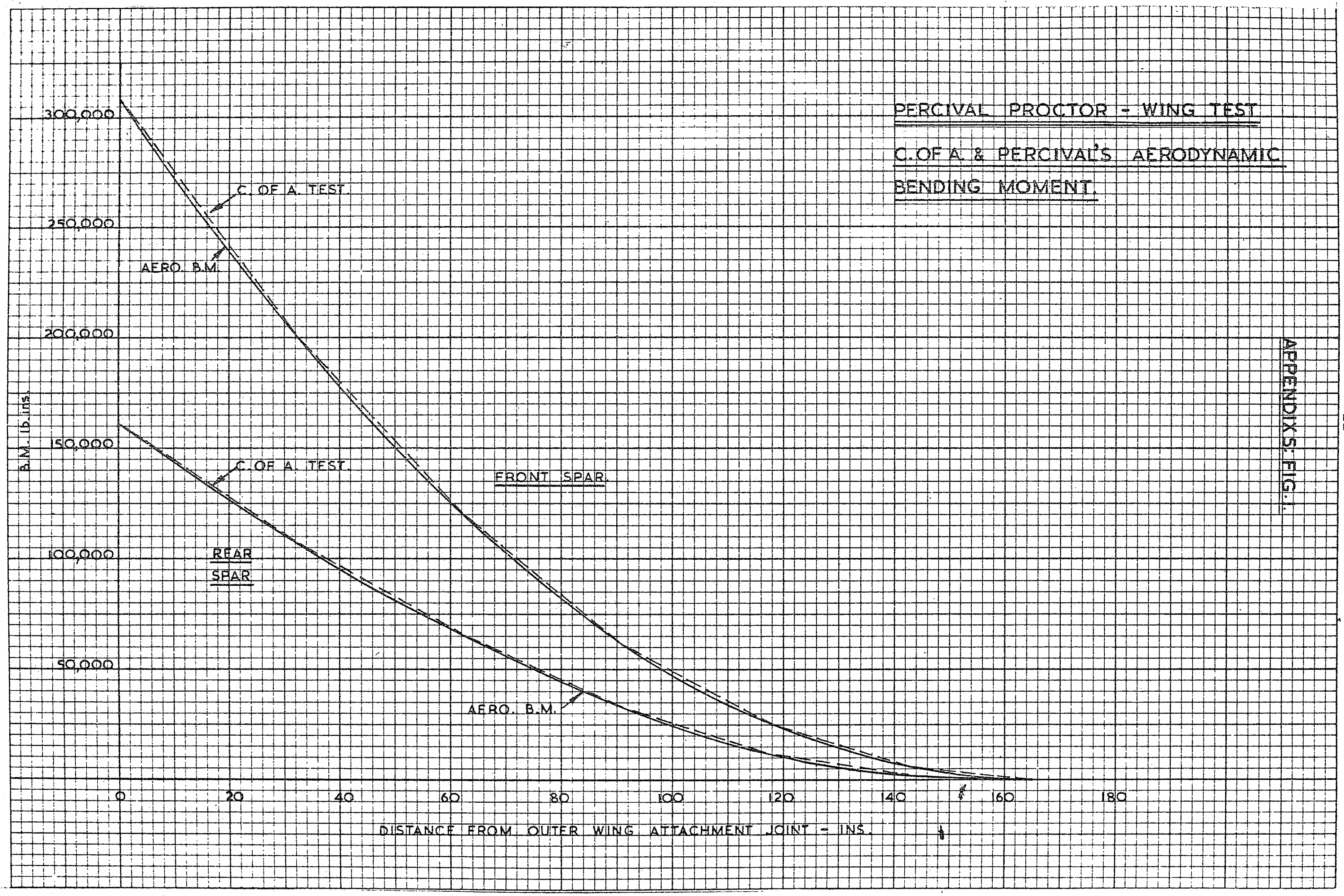
Case taken for test:

Case 3 in Miles Gemini Type Record (CP at LE)

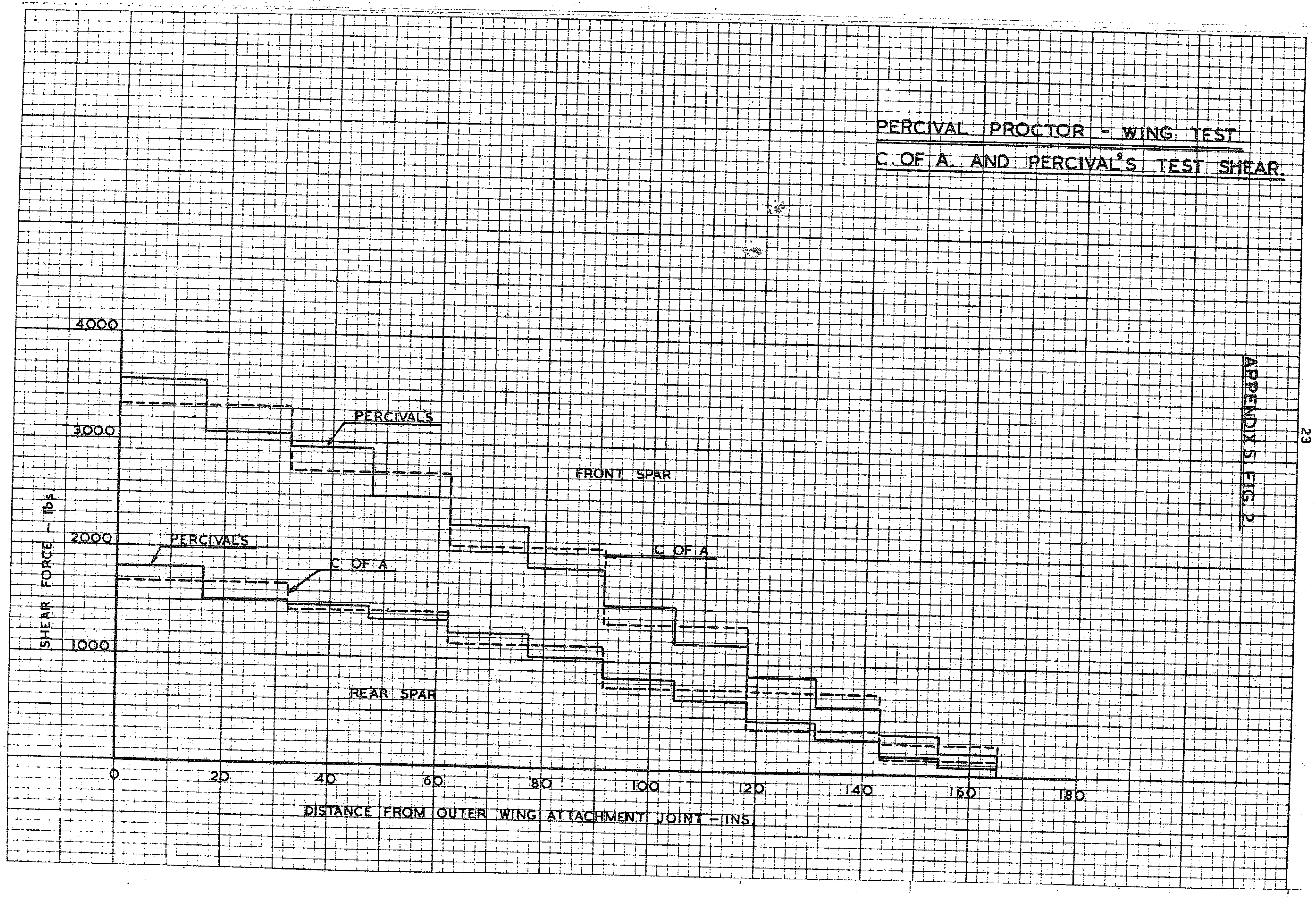
Rib	Dist. from ℄ of A/C (ins)	B.M. (lb.in)	Shear (lb)	Torque Acting About Rear Face of Spar (lb.in)
℄ A/C	0	22,000	0	-
A	5.8	21,000	705	17,400
B	14.9	14,400	580	14,300
C	21.0	11,300	510	12,600
D	26.8	8,800	420	11,200
E	33.0	6,700	340	9,400
F	38.8	4,800	255	7,800
G	44.6	3,500	175	6,600
H	50.6	2,600	100	5,200
J	56.7	2,200	20	3,800
K	62.0	2,200	-70	2,700
L	69.6	2,100	-20	1,000
℄ fin	73.6	2,300	-50	0

C of A Test Loading

Rib	Dist. from ℄ of A/C (ins)	B.M. (lb.in)	Shear (lb)	Torque acting about rear face of Spar (lb.in)
A	5.8	21,000	638	15,000
C	21.0	11,300	638	15,000
F	38.8	5,200	343	9,000
J	56.7	1,800	190	5,000
℄ fin	73.6	-	107	3,000

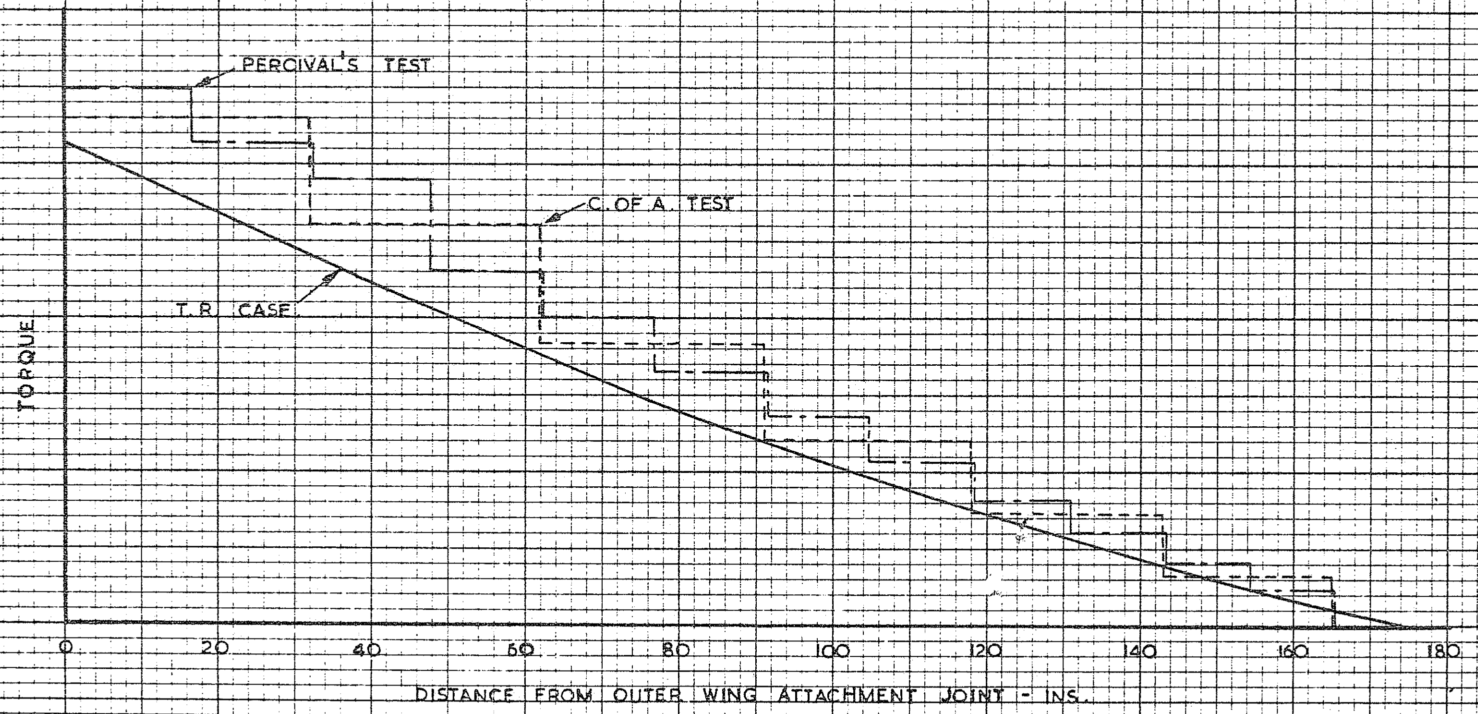


APPENDIX 5: FIG.

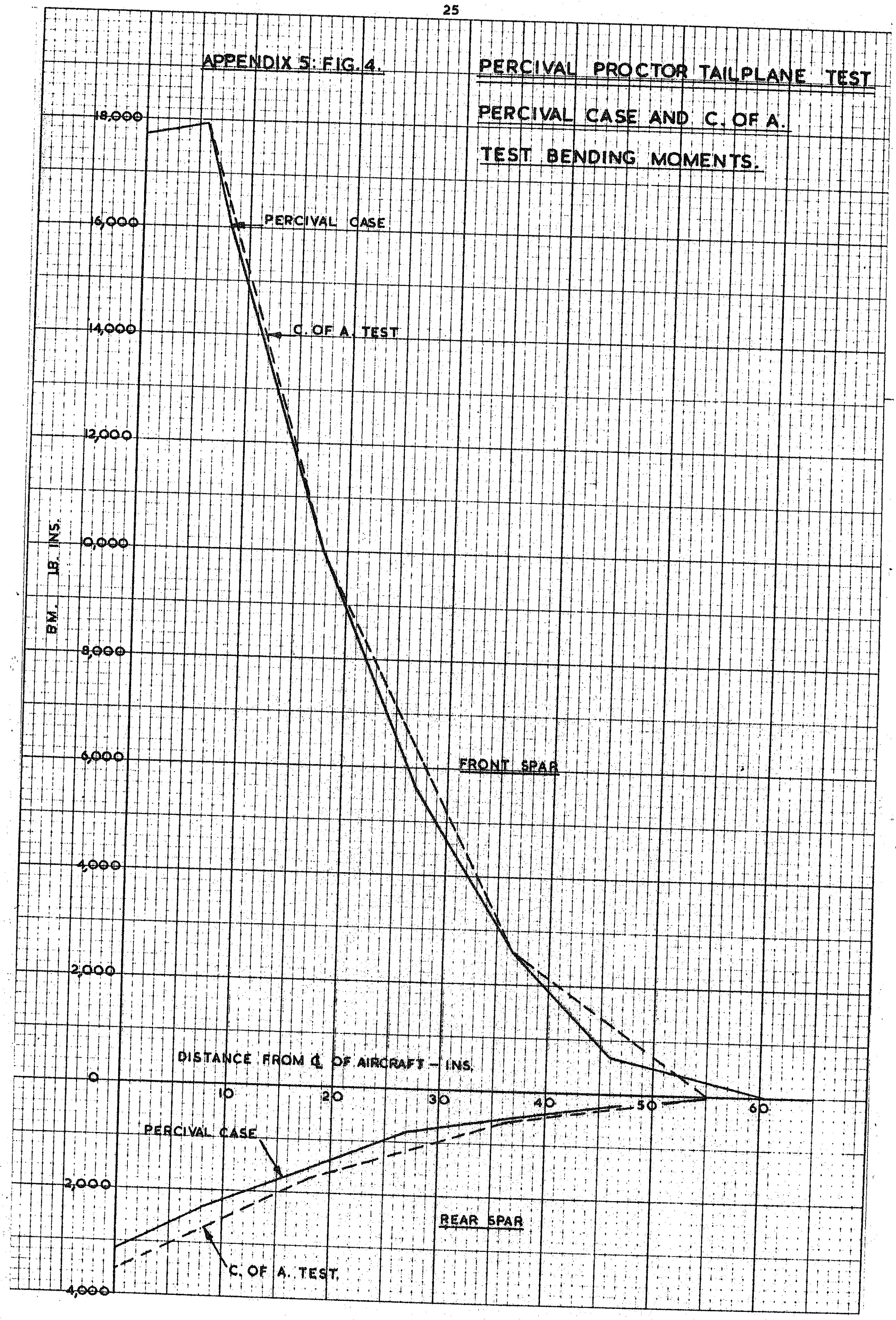


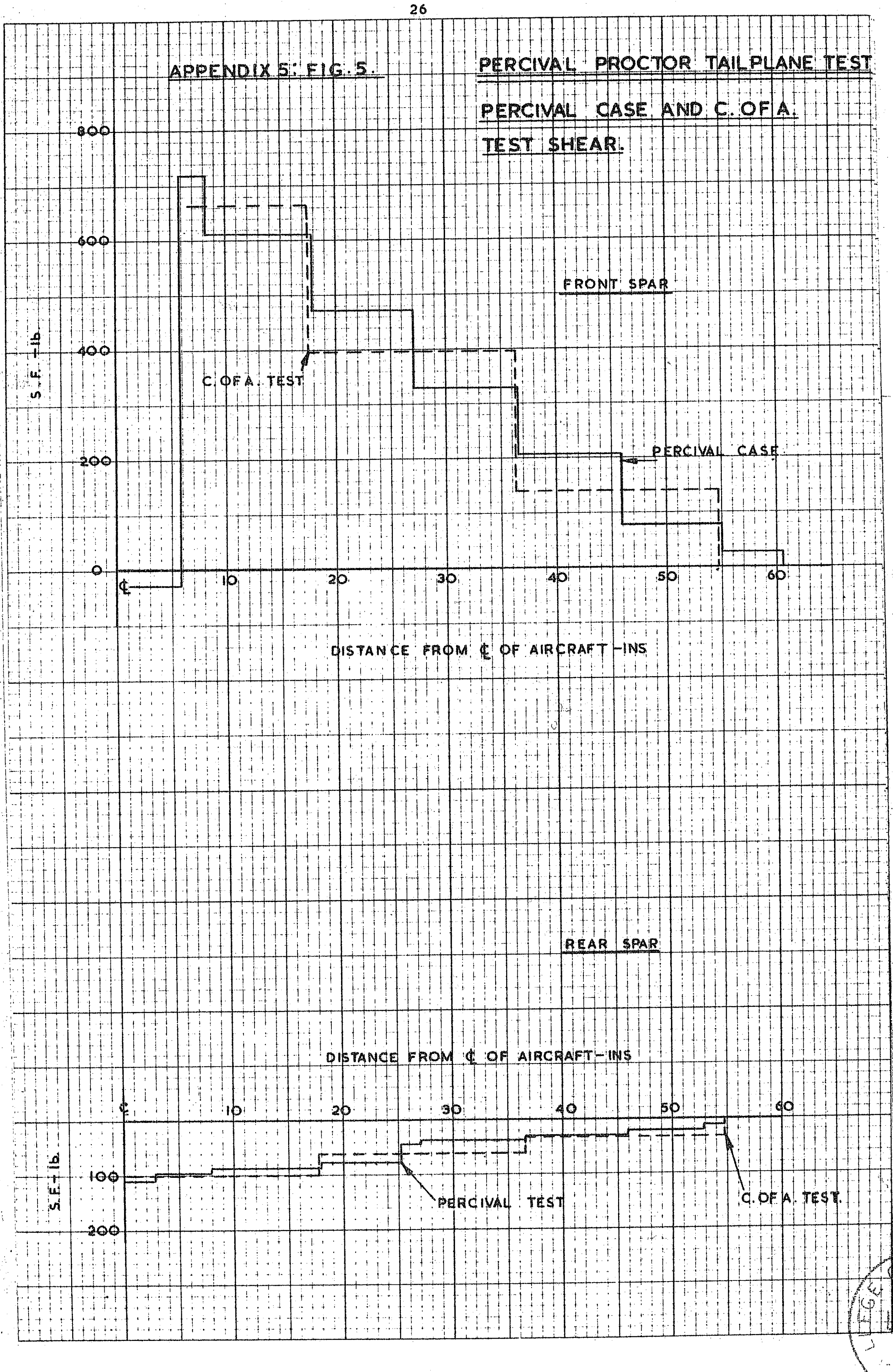
APPENDIX 5 FIG 2

PERCIVAL PROCTOR - WING TEST
TYPE RECORD CASE (C.P FWD),
PERCIVAL'S TEST CASE AND C. OF A.
TEST TORQUE COMPARISON.



APPENDIX 5 FIG. 3.


APPENDIX 5: FIG. 4.
PERCIVAL PROCTOR TAILPLANE TEST
PERCIVAL CASE AND C. OF A.
TEST BENDING MOMENTS.
B.M. LB. INS.
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2,000
4,000
PERCIVAL CASE
C. OF A. TEST
FRONT SPAR
DISTANCE FROM ℄ OF AIRCRAFT – INS.
10
20
30
40
50
60
PERCIVAL CASE
REAR SPAR
C. OF A. TEST



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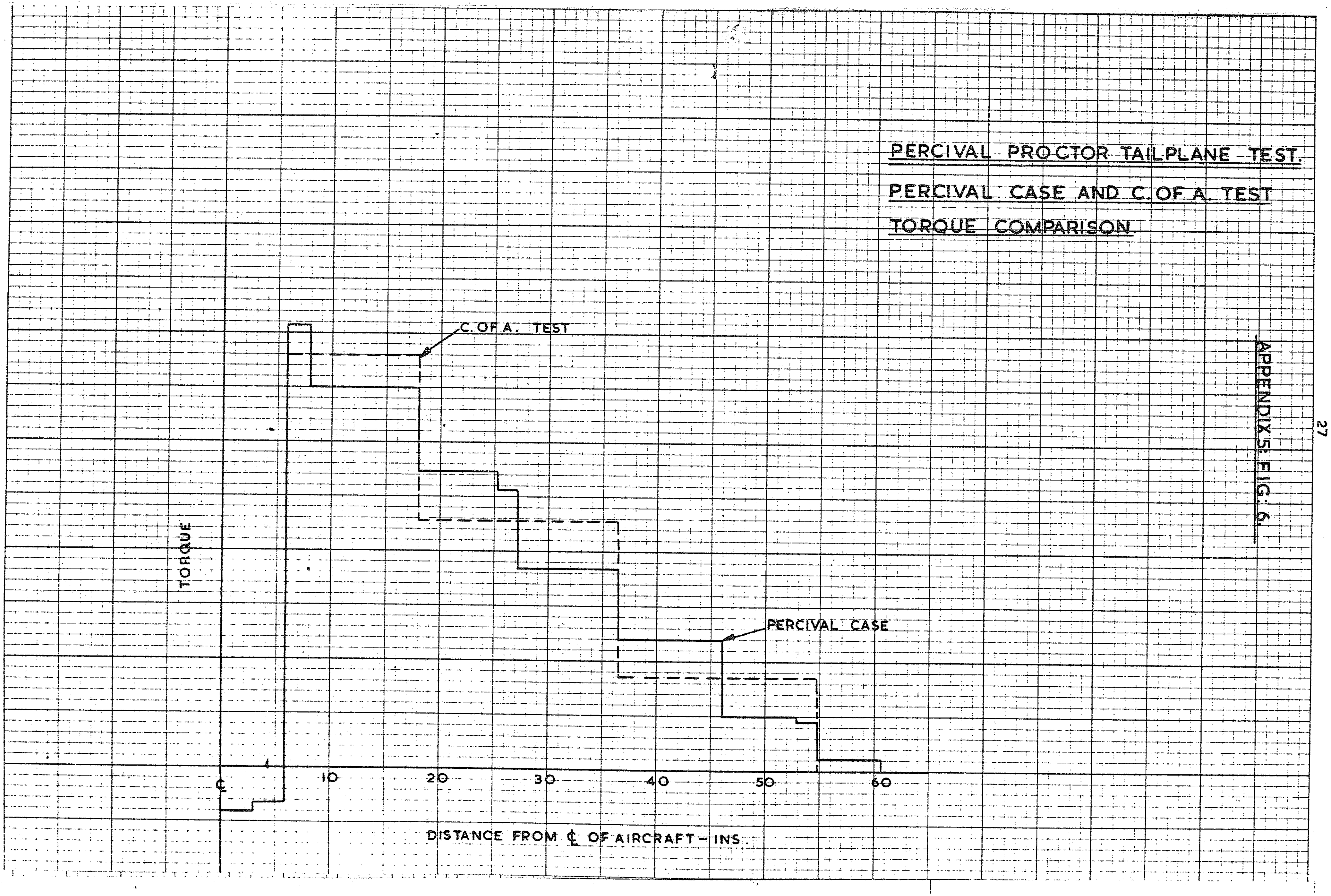
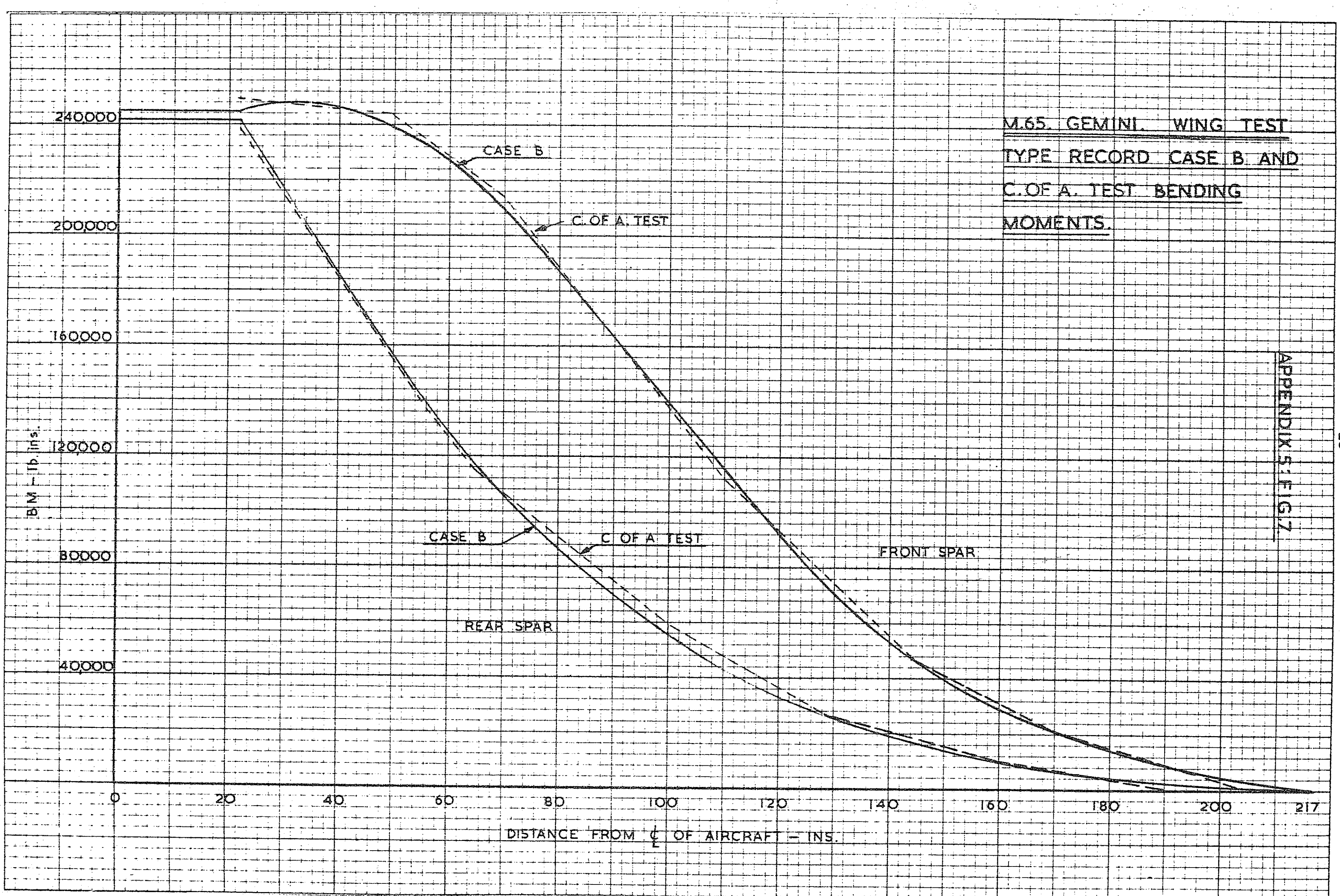
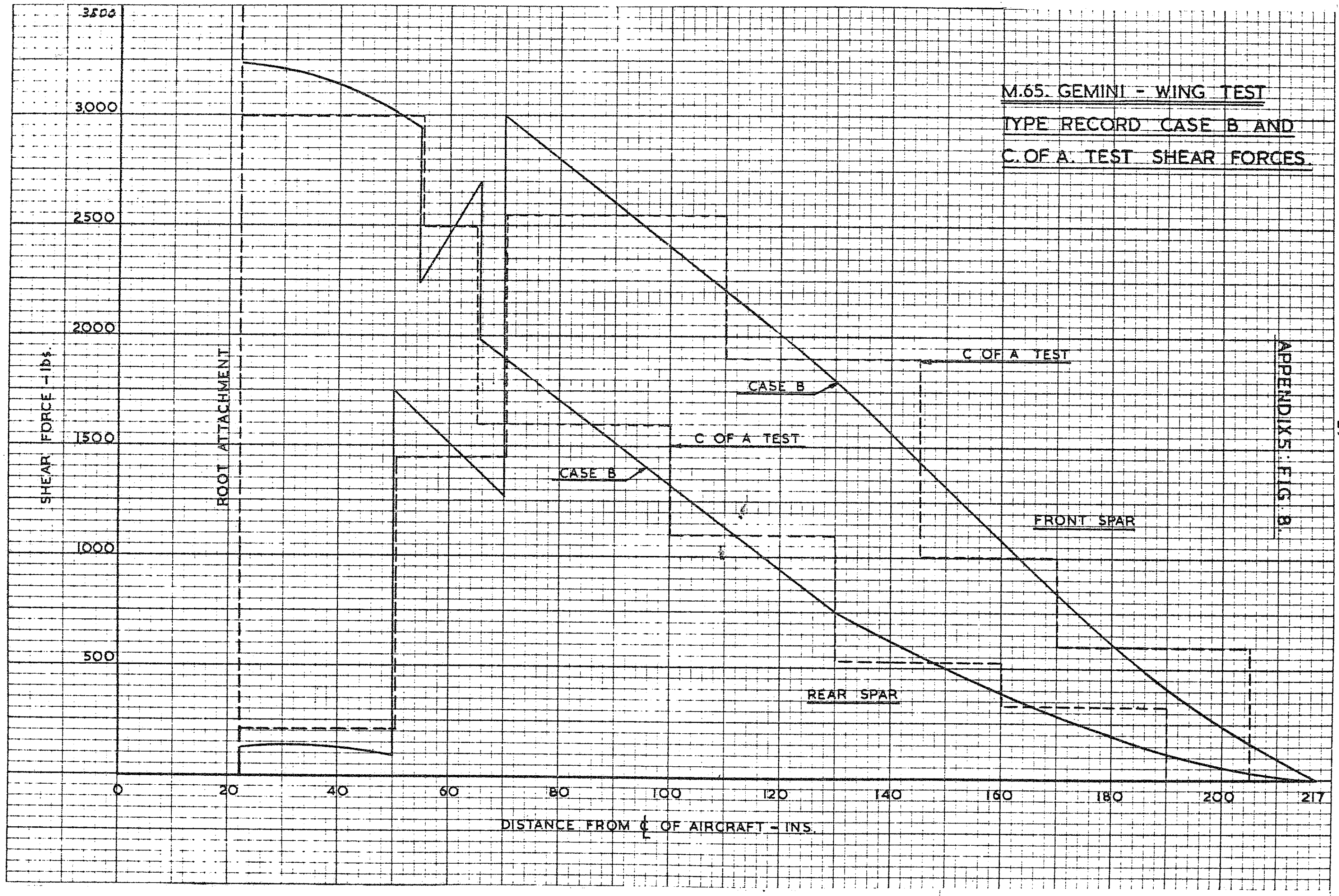


APPENDIX 5. FIG. 6.

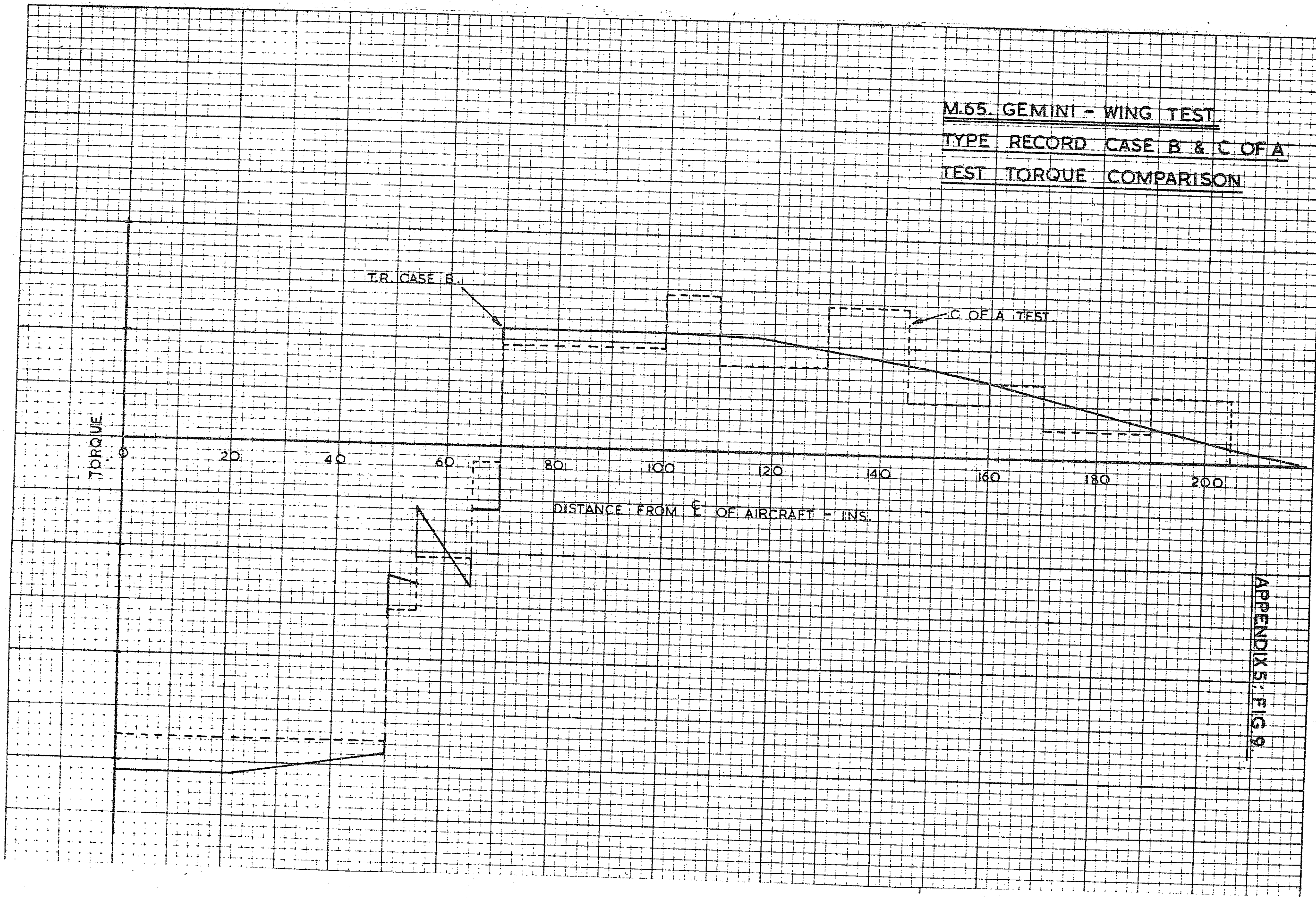


M.65. GEMINI. WING TEST TYPE RECORD CASE B AND C. OF A. TEST BENDING MOMENTS.

APPENDIX 5: FIG. 7

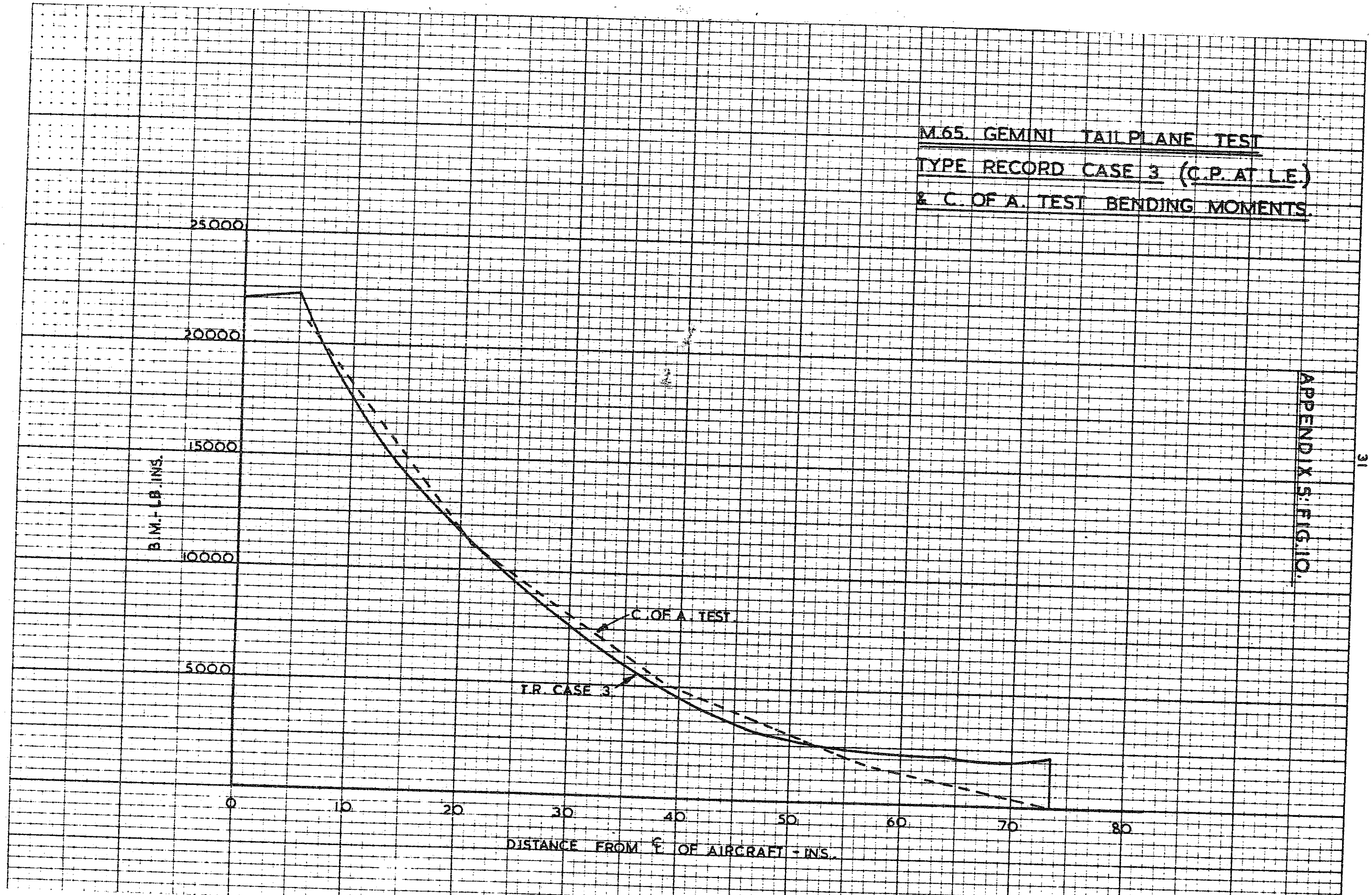


APPENDIX 5: FIG. 8.



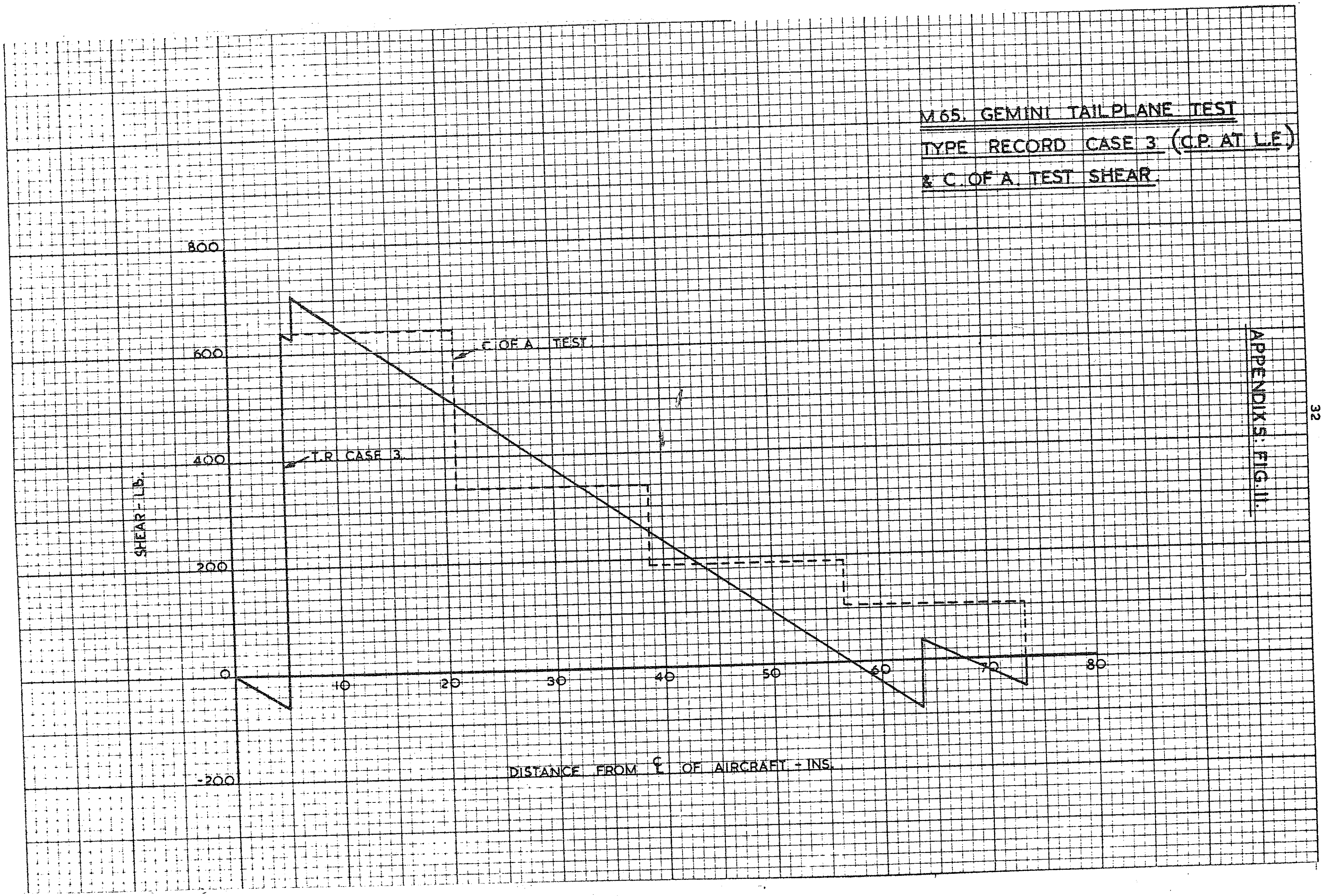
M.65. GEMINI - WING TEST.
TYPE RECORD CASE B & C OF A
TEST TORQUE COMPARISON

APPENDIX 5: FIG 9.

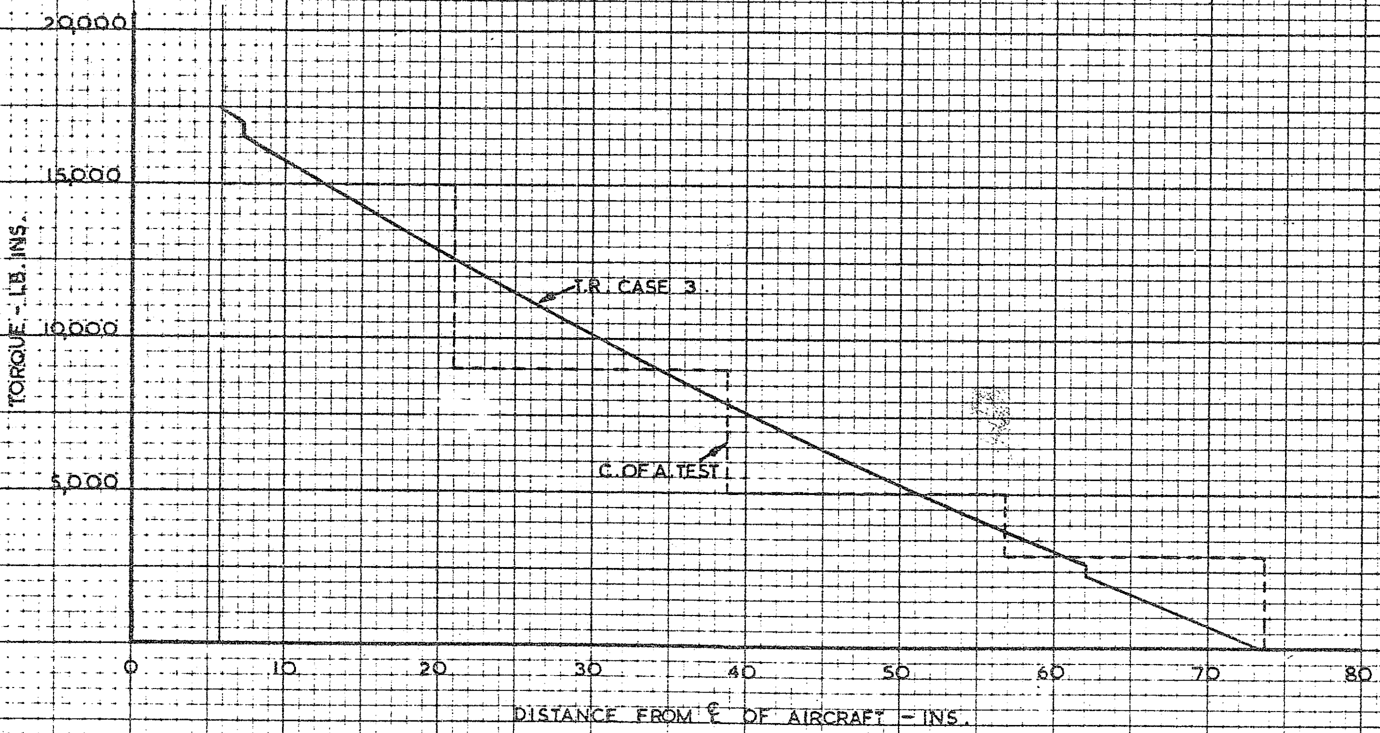


APPENDIX 5. FIG. 10.

APPENDIX 5: FIG. 11.



M.G.5 GEMINI - TAILPLANE TEST
TORQUE ABOUT REAR FACE OF
SPAR. TYPE RECORD CASE 3
(C.P. AT L.E.) & C. OF A. TEST.



APPENDIX 5. FIG 12.

APPENDIX 6

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

FOREST PRODUCTS RESEARCH LABORATORY

Destructive tests on Wooden Aircraft

Examination of glued joints in Gemini and Proctor wings and tailplanes

by R.J. Newall and L.S. Doman

November 1964

1. Introduction

After completion of destructive tests on the wings and tailplanes of Proctor and Gemini aircraft by the College of Aeronautics at Cranfield, specimens of the structure taken from or near the failures were sent to this Establishment for detailed examination and assessment of the condition of the glued joints. Results are listed in the report which follows.

2. Procedure for assessing quality of glued joints

Examination of the glued joints consisted either of pulling them apart manually, or prising apart with a chisel and assessing the quality of bond, mainly in terms of quantity of wood fibre adhering to the broken surfaces. The quality of adhesion was described as 'good' or 'poor'. This classification was based on experience but, as a rough guide, where wood failure occurred over less than about one quarter of the area this was described as 'poor'.

Where adhesion was found to be poor, clues to factors which could have affected the initial quality of bond were sought; the separated surfaces were also compared in appearance with those of B.S. 1204 type joints which, under test, had failed completely in the glue at a much reduced load as a result of age.

On the basis of these assessments the following classifications were defined:-

(A) Adhesion good.
(B) Adhesion poor, including cases indicative of faulty manufacture.
(C) Adhesion poor but indications of deterioration of glue with time.

(Where either B or C might affect the strength or airworthiness of the primary structure this has been indicated by an asterisk in the results listed in Para. 3).

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3. Results of forcible separation of glued joints

Note: The adhesive, except where stated otherwise, was urea-formaldehyde resin either used as a mixed glue or by the separate application method.

GEMINI WING SECTION - G-AJWC

Leading Edge Area

BOND CLASSIFICATION (See page 1)		
B*	(a)	Under side: 3 in. length of bond between main spar and skin defective where apparently there had been no contact between skin and spar. Remainder of bond between skin and spar was very poor there being practically no adherent fibre and a thick glue-line.
B*	(b)	Leading edge: Skin to ribs - patchy bond; areas of no contact 1 in. to 2 in. long.
B*	(c)	Upper side: Poor bond between main spar and skin; thick glue line throughout.

Petrol Tank Opening

B	Top. The inner of the double skin separated very easily with practically no fibre - thick glue line.
C	Bottom. The thin inner skin of the floor below the petrol tank peeled off like paper with 100 per cent glue failure though apparently good contact initially.
B	Bond between outer skin and floor framing was very patchy.

Main Surface - Top: Skin peeled off with ease though no lack of fibre.

A	Some U.F. bonded ply over and to the side of the petrol tank; this, however, apparently sound.

Main Surface - Bottom: Bond between skin and spar and between skin and ribs

A	good - 100 per cent wood failure.

Bulkhead between wing and petrol tank space. Plywood separated easily from

C	framing with practically no fibre though again evidence of good contact initially. Concluded that glue had deteriorated.

Front spar - Before dismantling, a crack was found in each web though these may have occurred while the skin was being removed.

B* Internal frames were easily removed; practically no wood fibre where bonded to birch skin but more in softwood joint; good initial contact in all joints.

Bottom boom had fractured presumably during the mechanical test (oblique) over a length of 21 in. A tiny compression failure in top boom just above the brace.

B* Bond between birch plywood and softwood booms was variable; some failure occurred in the plywood while on both booms separation could be effected over a large area mainly in the glue line.

Rear Spar - A In separating webs from booms the failure was largely in the softwood booms and generally deep.

General - Some of the bonding found in this wing was attributable to shortcomings in manufacture and some appeared to be due to deterioration of the glue though no glue line failure occurred during test even though the booms of one of the spars failed.

GEMINI WING SECTION - G-AJWF

A As received the skin had been torn away from the front spar along a length of about 3 ft; about 60 per cent of the separated area showed deep wood fibre and the remainder fine fibre.

Leading Edge area - A Separation of the skin from the ribs showed bond quality varying from tearing in the ply itself via an almost glue line separation but with fine adherent fibre, to complete glue line

B* separation; the latter resulted from lack of contact between ribs and skin initially.

Main Surface - Top - Double Skin. Both upper and lower skins of this portion could be separated without adherent fibre but since contact

B* in many places had been insufficient to transfer the dye from the plywood surface spread with hardener to the glue spread on the softwood it might be assumed that the bond had never been good.

Trailing Edge Area - Top Skin - Practically no bond over about 90 per cent of

B area.

Lower Skin - A This was easily knocked off the two ribs one showing about 90 per cent wood fibre, the other about 50 per cent.

Skin to Front spar - Upper skin - Largely removed before receipt with

A mainly wood failure.

B* Lower skin - On a length of 12 in. to 15 in. at the root end the skin separated easily from the spar leaving no adherent fibre. The remainder of the length was much better bonded on the after portion but a strip along the

A forward edge of the spar had not contacted well, the plywood

B* being apparently held off the spar by an over-riding scarf joint.

Skin to rear spar. Upper skin - The forward part was bonded well, failure

A during forcible separation occurring in the plywood, but along a strip towards the after edge the skin was again held

B* off by a badly fitting scarf resulting in a consequent thick glue line.

B* Lower skin - A length of about 12 in. at the root end was easily removed with separation completely in the glue line, the remainder was more difficult to remove but still showed mainly glue line separation.

Webs to booms in spars - Separation of plywood webs from softwood booms was

B* fairly easy with complete glue failure.

Skin to tank bulkhead - Separation easy with glue line failure; since there

C were no signs of shortcomings in manufacture concluded that deterioration of bond had occurred.

General - There were considerable areas of poor bond quality, some of which could be associated with inadequate contact initially; in some cases this was due to badly fitting scarfs, lack of contact also occurred on the extreme leading edge of the wing where the curve of the ribs did not fit that of the skin. Some of the poor bond quality was considered to be due to glue deterioration.

GEMINI WING SECTION - G-AMGF

This section was about 18 in. long. As received the skin had been largely removed from the ribs and the lower boom of the front spar had been split off leaving deep fibre about $^1/_4$ in. thick adhering to the skin. This was stained with purple hardener indicating that the boom had been split when a gluing operation was carried out; this could have been a repair. There was deep fibre from the ribs adhering to both upper and lower skins but near the leading edge the amount of adherent fibre was very small.

Skin to Front spar - A length of about 4 in. at the root end separated
B* in the glue line and the remainder showed about 50 per cent
A wood failure mostly torn from the skin.

Skin to Rear spar - Adhesion very variable, some failure occurring
B* completely in the glue line and some in the plywood; some of the glue line was very thick (greater than 1 millimetre).

Webs to Booms - Generally the plywood webs could be removed easily with
B* separation completely in the glue.

Trailing Edge Fairing - Skin ripped off easily, not more than 10 per cent
B fibre from ribs on failed surface.

C A hinged hand-opening framed with thin birch ply, glued and bradded, was examined. The framing had separated from the skin all round and nearly fell off; the failed surface had no adherent fibre. It appeared that a repair had been carried out at the fastener-end of the opening, possibly because of failure in the glue caused by the stress of pulling open the cover.

A The bond between the skin and the wedge of spruce at the extreme trailing edge was good, wood failure being about 80 per cent.

Rear spar - Thin plywood stiffeners bonded to the web with casein showed separation in the glue when forced off. The bond between
A the plywood webs and the spruce booms was good, varying between about 75 per cent and 100 per cent separation in the wood.

General - The bonding was again very variable though the proportion in the higher range was greater.

PROCTOR WING SECTION - G-AHBA (Port wing)

On the underside of the front spar there were splits in the boom extending from the bolts holding the connector lugs. On the underside of the rear spar the boom had split away from the ash stiffener along the whole length of the section.

Leading Edge - Excellent bond between skin and ribs particularly at
A bottom.

Front spar - Failure during test had occurred in the lower spruce boom, but not accompanied by failure in the glue lines.

A Bond between top boom and webs failed partly in the plywood (about 50 per cent) and partly in the glue. That between the bottom boom and the webs failed with deep wood failure in the booms.

Rear Spar. Bottom boom - A split had developed during test in the boom just outside the inner line of bolt holes and the boom together with web had moved about $^1/_4$ in. outboard.

The ash stiffener with the plywood corner brace must have failed during test, not by glue failure but with deep tearing of softwood fibre. All the bolt holes in the ash were circular.

B A stiffener along the centre of the inner web was held by screws and glue but on removal of the screws it was found that the glue had previously failed almost completely.

Top boom - Bond between ash stiffener and boom failed with practically

B no wood fibre. The bond between the webs and the booms

B* was very varied, that with the top boom separating almost completely in the glue line while with the bottom boom separation occurred sometimes in the plywood and sometimes

A in the softwood fibres of the boom.

Struts joining the two spars -

A In general the bond between two softwood members failed with deep tearing of fibre but that between plywood and softwood

B* showed practically no adherent fibre.

General - Bonding was again variable though the proportion of well bonded glue lines was predominant.

PROCTOR WING SECTION - G-AHGJ

The only pieces received of this wing consisted of (1) one half of a spar largely in pieces, (2) the root box-section of trailing edge spar with metal connections.

A (1) Bonds between plywood and boom, between ash strip and boom and between the laminations of the boom were all apparently good.

(2) A birch plywood sheet was interleaved between the ash stiffener and one of the booms and this could be separated from the boom by a single blow; the separated surfaces showed

B only fine fibre and there was a black stain covering the softwood; this stain had been partially transferred to the plywood and it was suspected that this might have been some form of surface contamination which could have affected the bond.

A The ash stiffener on the opposite face of the spar was much more difficult to remove and separation was accompanied by deep wood failure.

General - With the exception of the possibly contaminated surface all joints were quite well bonded.

GEMINI TAILPLANE SECTION - G-AJWC (Inspection Mark 24/3/47)

B* Separation of the skin from the ribs could be effected largely in the glue lines; in some areas this was attributable to insufficient contact initially ('islanding') but other joints had been well bonded initially and had the appearance

C* of having deteriorated with age, the glue remaining as a cast in the vessels of the birch plywood. Incidentally a piece of badly bonded plywood was encountered, the film glue having the characteristic appearance of 'pre-cure'.

GEMINI TAILPLANE - G-AJWF

C* The bond was extremely variable, some joints between ribs and skin separating completely in the glue line and some almost entirely in the ply. There was no direct evidence of faulty manufacture and it must be concluded that areas of glue failure were due to deterioration of glue.

PROCTOR TAILPLANE - G-AHGJ

Rear Spar - The lower skin separated from the boom fairly easily with

B* rather less than 10 per cent adherent fibre whereas the

A upper skin failed almost entirely in the plywood.

Ribs to lower skin - Separation could be effected mainly in the glue line

B* in one case; entirely glue line separation in the other.

Ribs to upper skin - Separation resulted in 50 per cent wood failure in one

A case; less than 5 per cent wood failure in the other.

B*

Curved ribs on leading edge - Separation effected completely

B* in the glue line.

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Front spar - A — The lower skin was separated from the boom, leaving deep wood failure on the skin, while with the upper skin, failure occurred almost completely in the plywood.

General - Again the bonding was very variable; there was evidence of faulty contact to account for glue failure between the curved leading edge ribs and the skin and much of the other glue failure showed 'islanding'.

4. Discussion of results

The quality of adhesion was extremely varied and often covered the range of classifications defined in para. 2; in class A, separation sometimes resulted in fracture within plywood and sometimes in the adjoining solid softwood. Examples of class B included cases of insufficient glue to fill the gap between two surfaces, sometimes accompanied by the characteristic 'islanded' appearance which results from partial release of bonding pressure before the glue has set; in other examples there was complete absence of contact between the two surfaces. Areas of partial contact were found along the booms where scarfs in the plywood were usually over-riding. Other areas of poor adhesion, including those attributable to glue deterioration (class C) were not associated with any particular part of the structure.

5. Conclusions

The effect of the weakened bonds on the strength of the aircraft is difficult to assess since glued joints frequently have a large margin in hand and can tolerate some imperfection and/or deterioration of the glue itself.

This is borne out by the mechanical tests on the wings and tailplanes where, with one exception, the failures were not initiated by weakness in the glued joints.

Even in the case of the one Gemini tailplane in which the test was terminated by glue failure, this occurred at a very satsifactory figure of 115 per cent F.F.L. This does, however, represent an appreciable reduction in strength when compared with the other two Gemini tailplanes.

It should be borne in mind that flight conditions were not simulated exactly during the structural tests, for example, local air loading over the surfaces was not present - hence unsatisfactory joints between skin and spar of the type found during the detail analysis could possibly cause failure in flight at a load value less than that obtained during test.

Although detailed reading of the results in paragraph 3 might lead one to believe that the overall condition of the structural specimens was poor, it should be emphasised that, based on experience of some similar tests on parts of aircraft carried out in the past we consider the condition was at least average.

List of figures

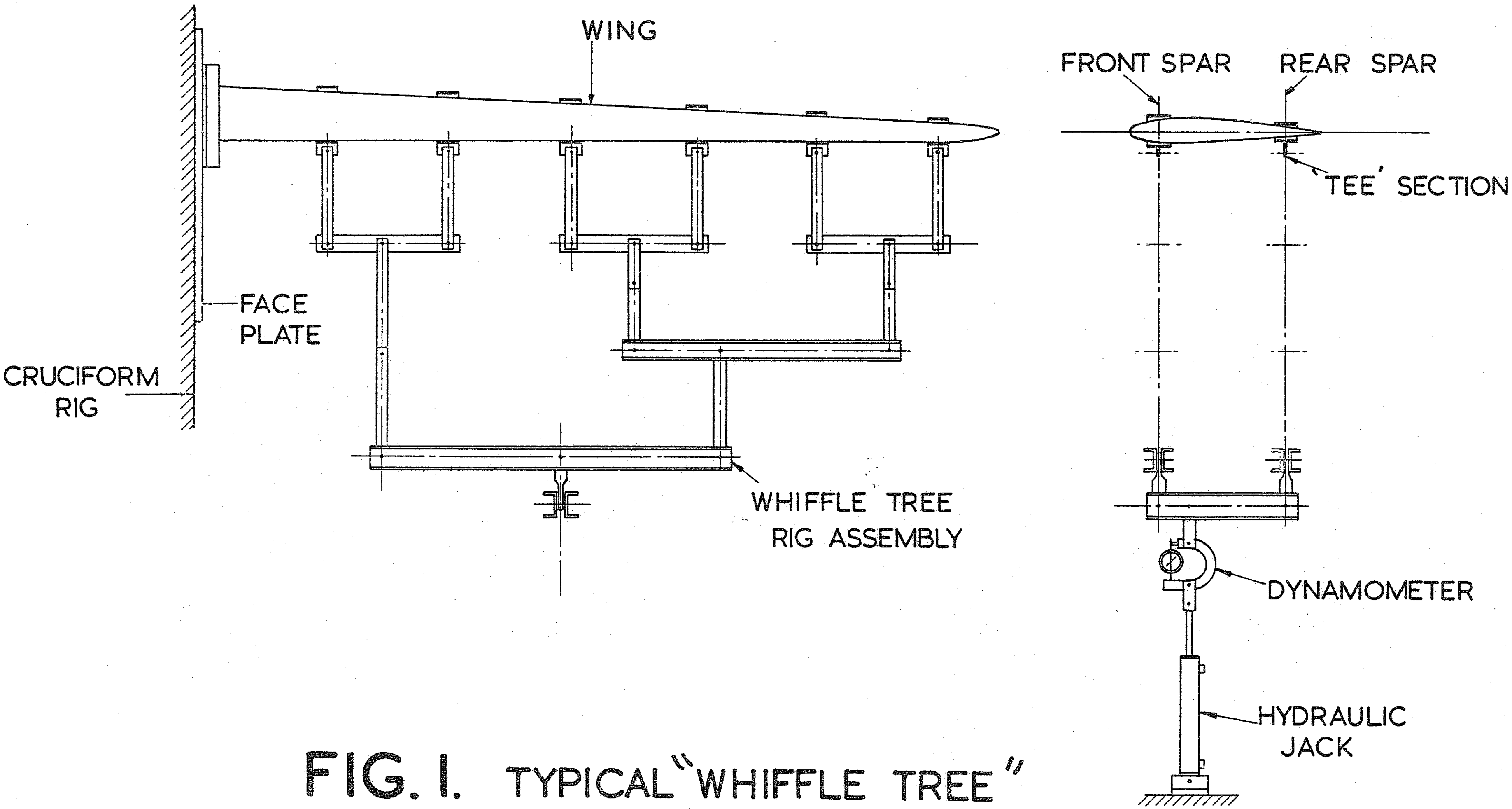

FIG. 1. TYPICAL "WHIFFLE TREE" LOADING RIG.

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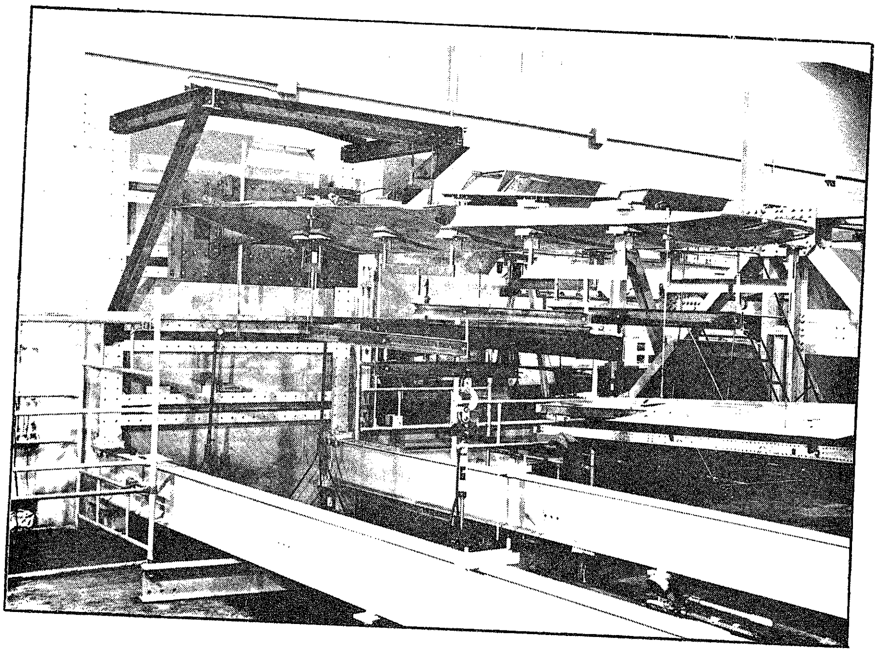

FIG. 2. GENERAL VIEW OF GEMINI WING SECTION ON TEST RIG PRIOR TO TESTING.

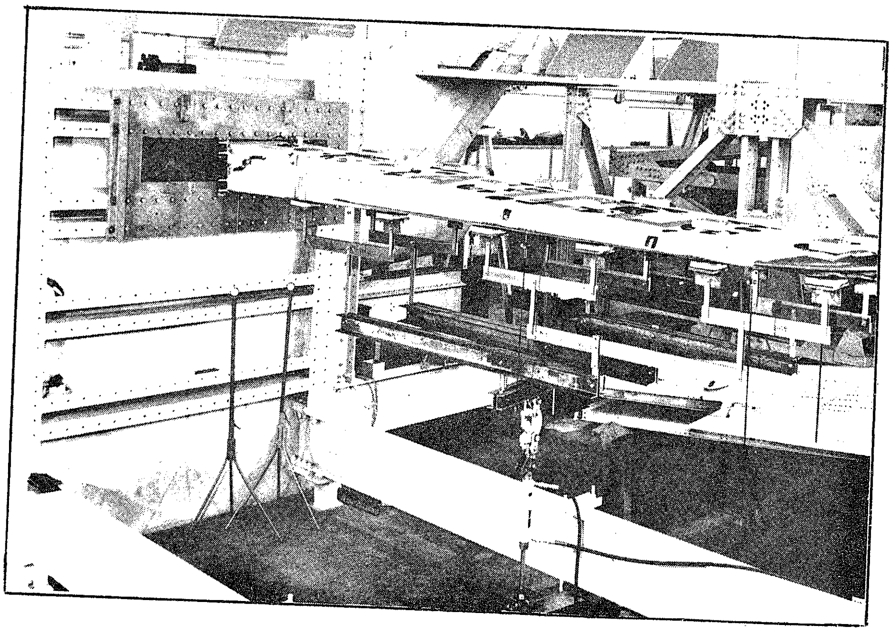

FIG. 3. PROCTOR OUTER WING BEFORE TEST.

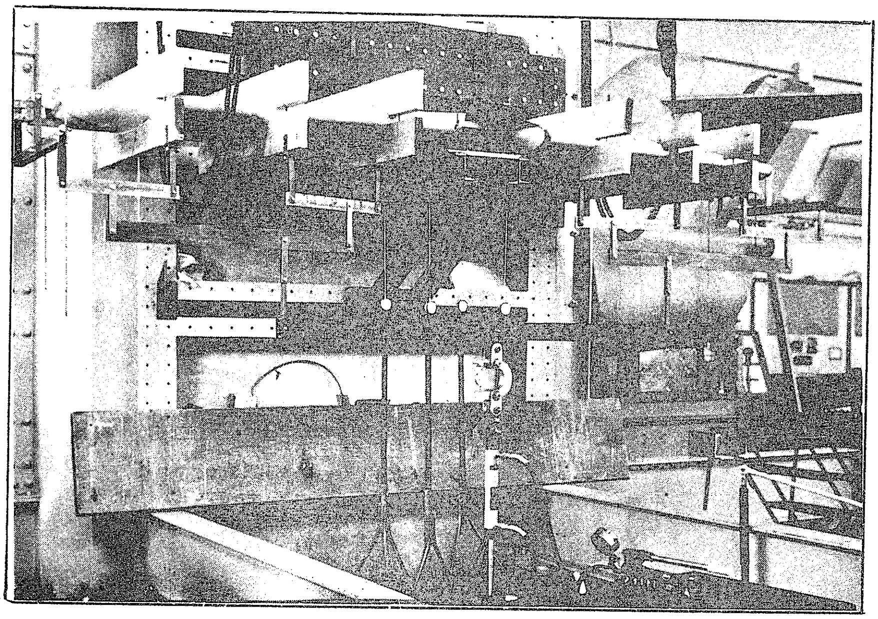

FIG. 4. GEMINI TAILPLANE MOUNTED OFF THE RIG FACE PLATE BEFORE TEST.

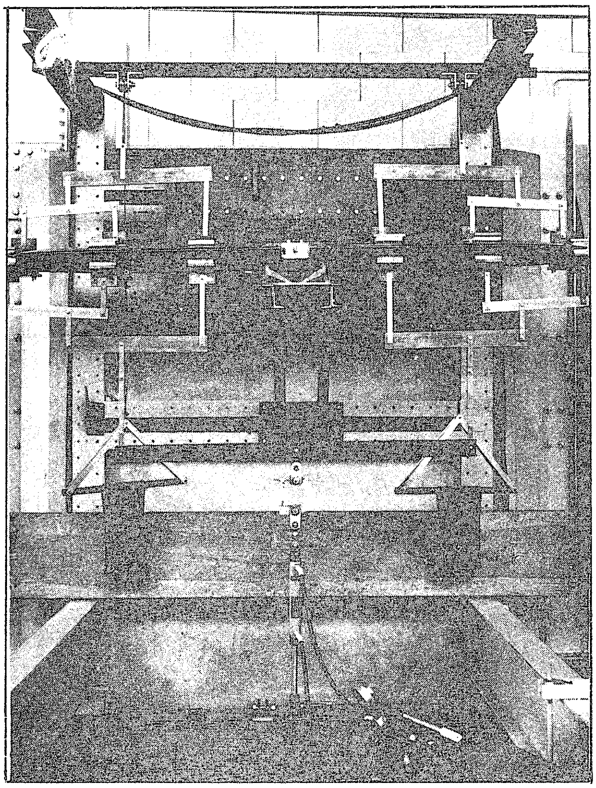

FIG. 5. PROCTOR TAILPLANE PRIOR TO TEST SHOWING "WHIFFLE TREE" LOADING RIG ASSEMBLY.

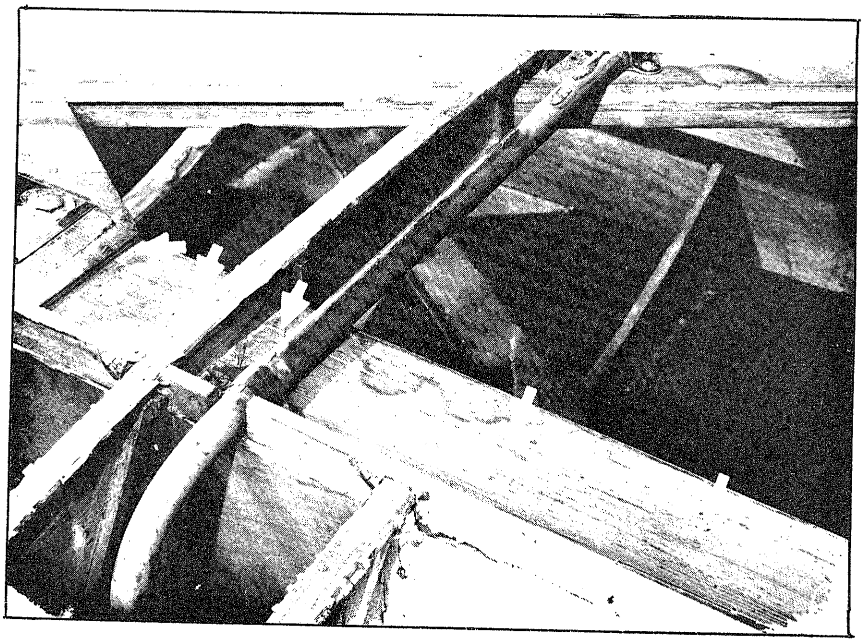

FIG. 6. TYPICAL LOWER BOOM FRONT SPAR FAILURE - PROCTOR OUTER WING.

FIG. 7. CLOSE UP OF BOOM FAILURE OUTBOARD OF OUTER WING ATTACHMENT BRACKET. PROCTOR.

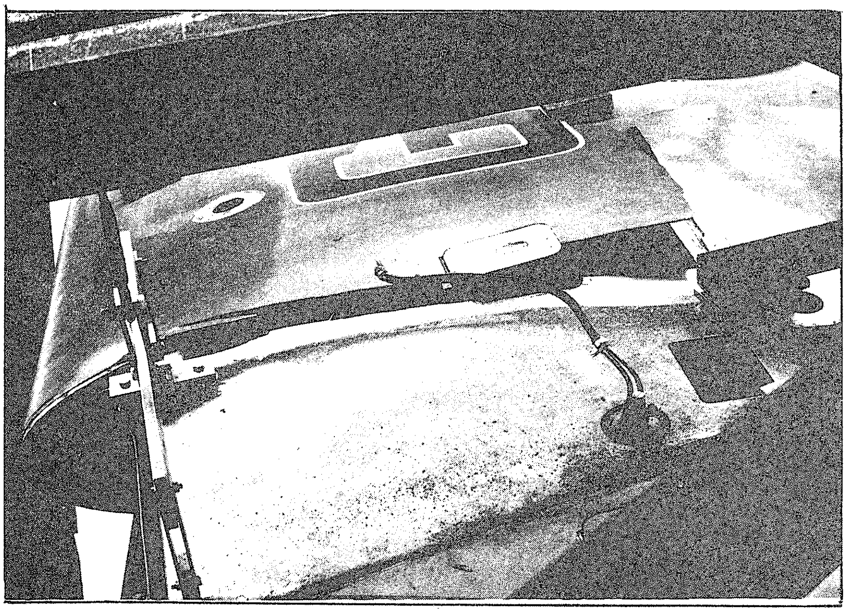

FIG. 8. PORT WING TOTAL FAILURE. GEMINI G-AJWC.
SHOWING TYPICAL POSITION OF SKIN SPLIT
(INITIAL FAILURE).

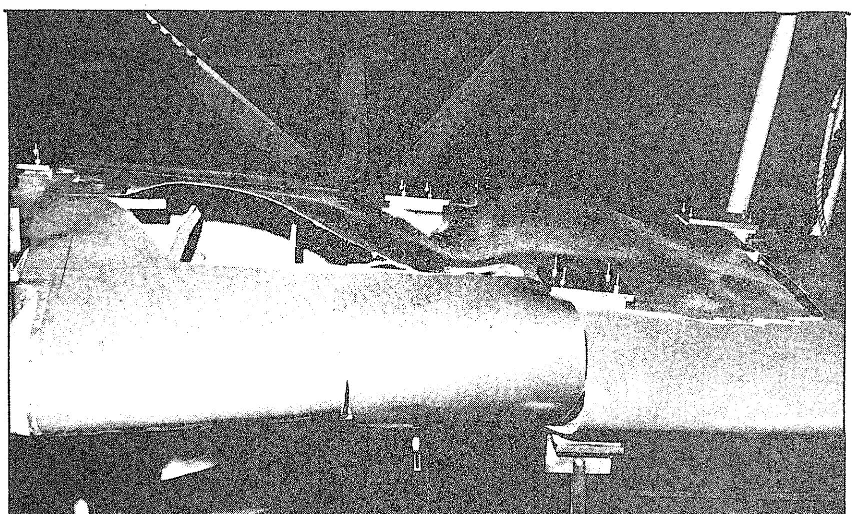

FIG. 9. GEMINI G-AJWC. STARBOARD WING. TOTAL FAILURE
OF BOTH SPARS AND WING STRUCTURE.

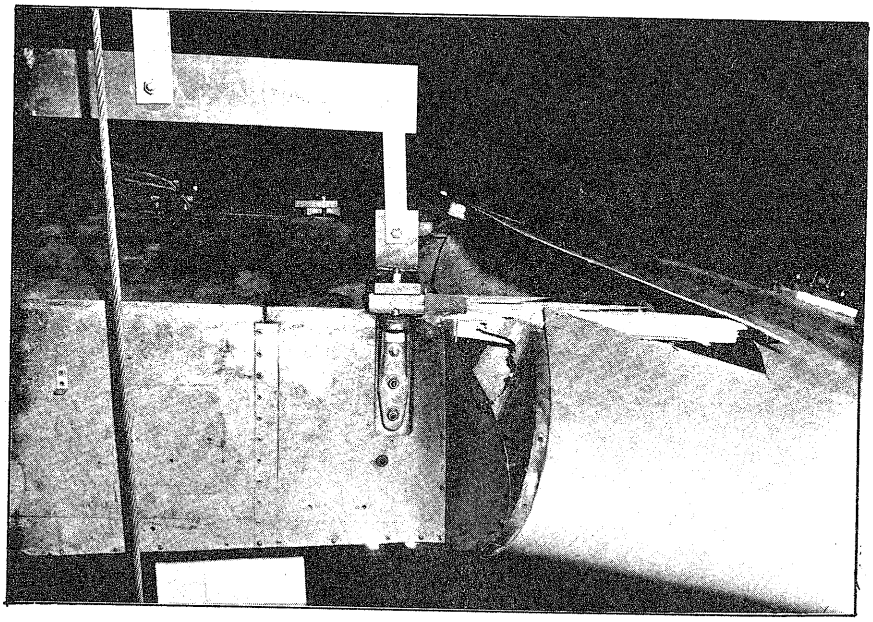

FIG. 10. TOTAL FAILURE POSITION, JUST OUTBOARD OF ENGINE ATTACHMENT BRACKET. GEMINI G-AJWF (STARBOARD WING).

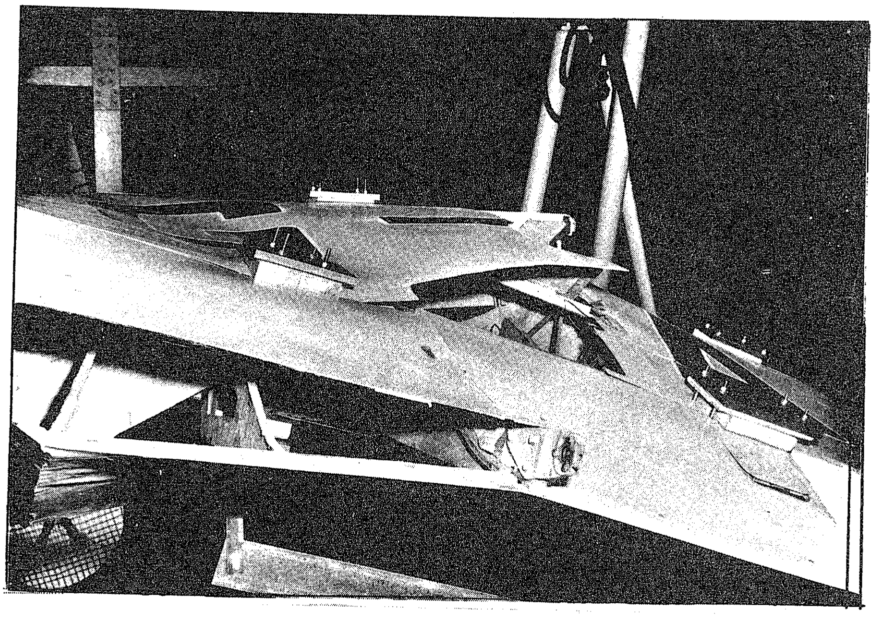

FIG. 11. TOTAL COLLAPSE OF PORT WING GEMINI G-AJWF.

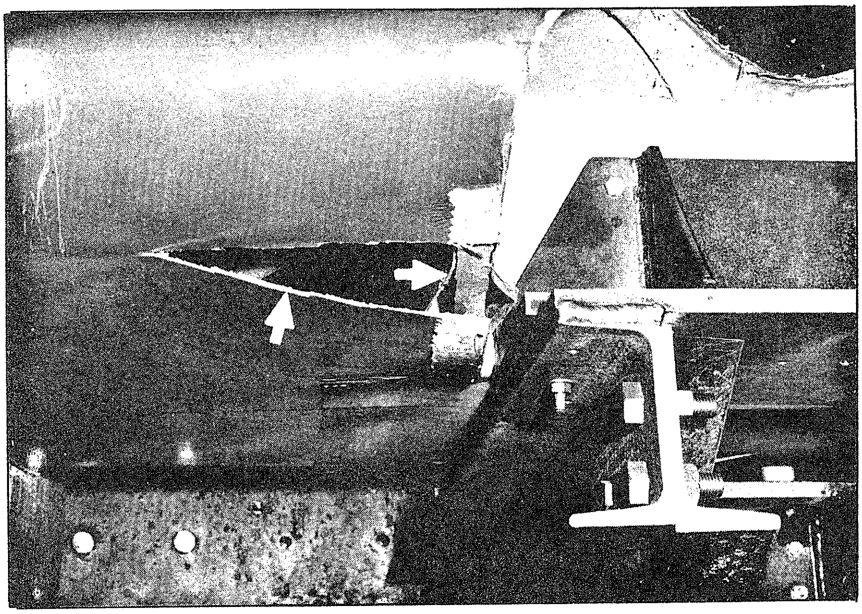

FIG. 12. SKIN SPLIT AND GLUE JOINT FAILURE AT THE ROOT, GEMINI G-AJWC TAILPLANE.

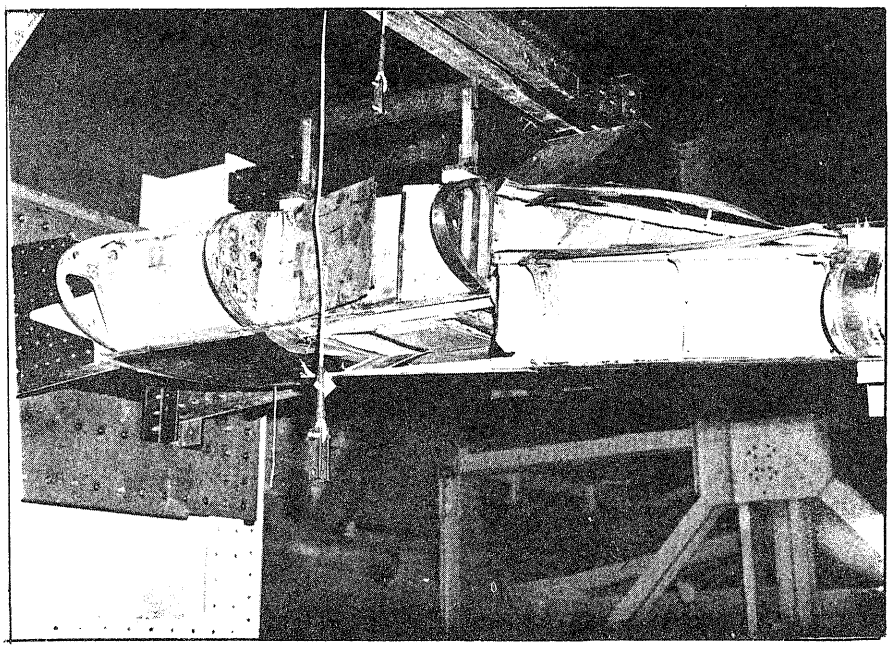

FIG. 13. TYPICAL COLLAPSE OF STARBOARD WING, GEMINI MK. VII G-AMGF.

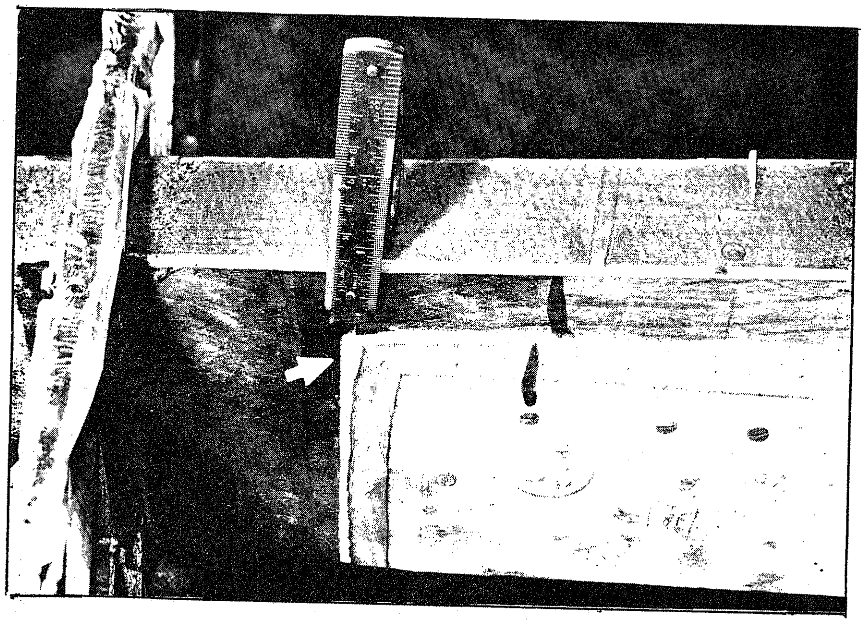

FIG. 14. DEFECT. PROCTOR PORT WING. G-AHBA.
INSPECTION PANEL LIFTING AT CORNERS.

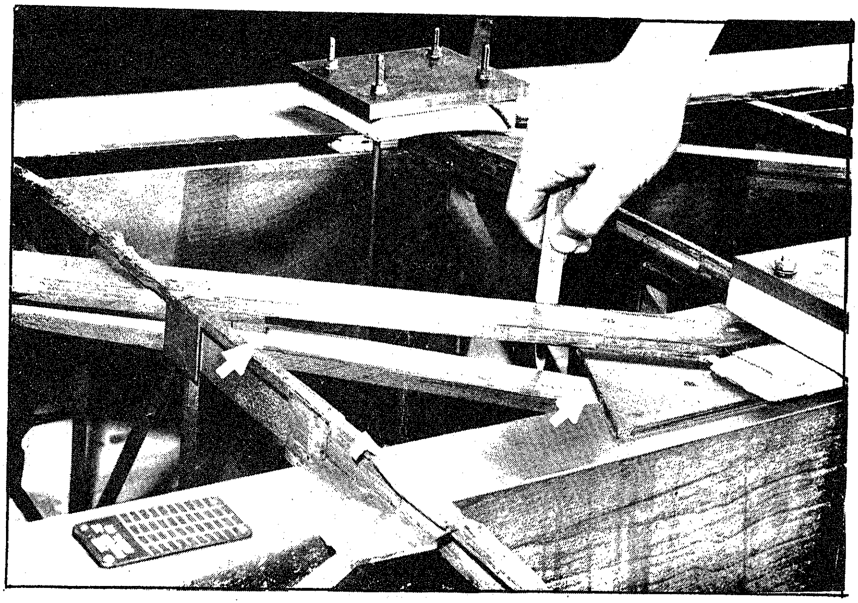

FIG. 15. DEFECT. SAME WING SECTION AS FIG. 14. DRAG
BRACE TOTAL GLUE JOINT FAILURE.

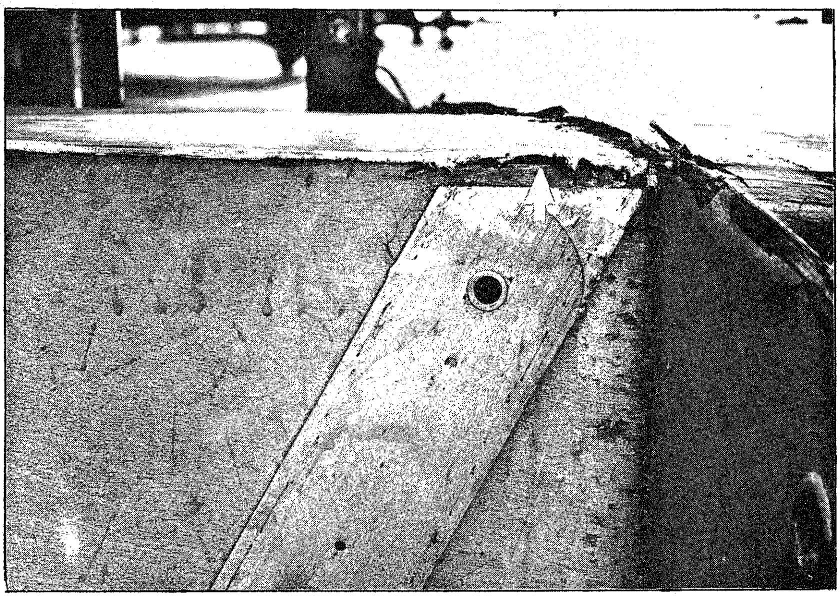

FIG. 16. GEMINI G-AJWC. SKIN LIFTING AT CENTRE SECTION OF TAILPLANE.

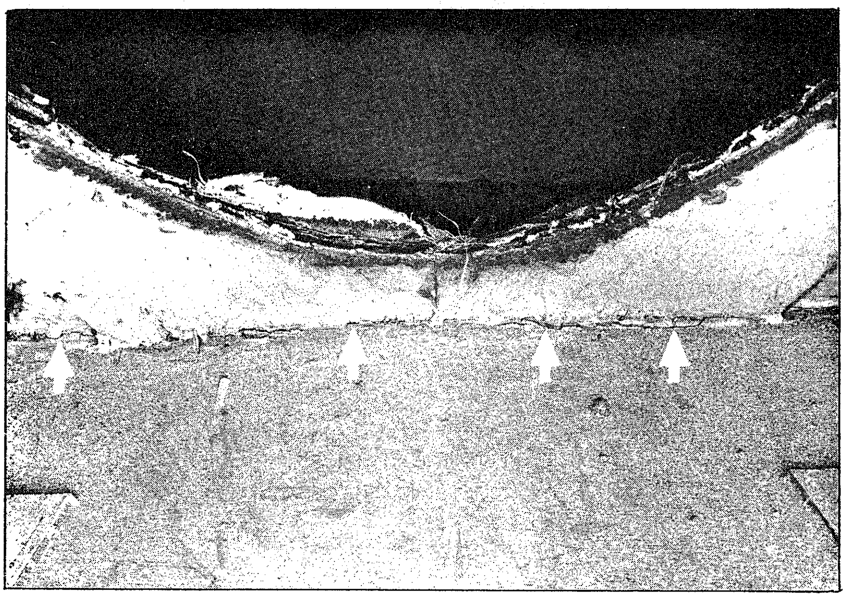

FIG. 17. DIAPHRAGM/TOP SKIN GLUE FAILURE. GEMINI G-AJWC TAILPLANE.

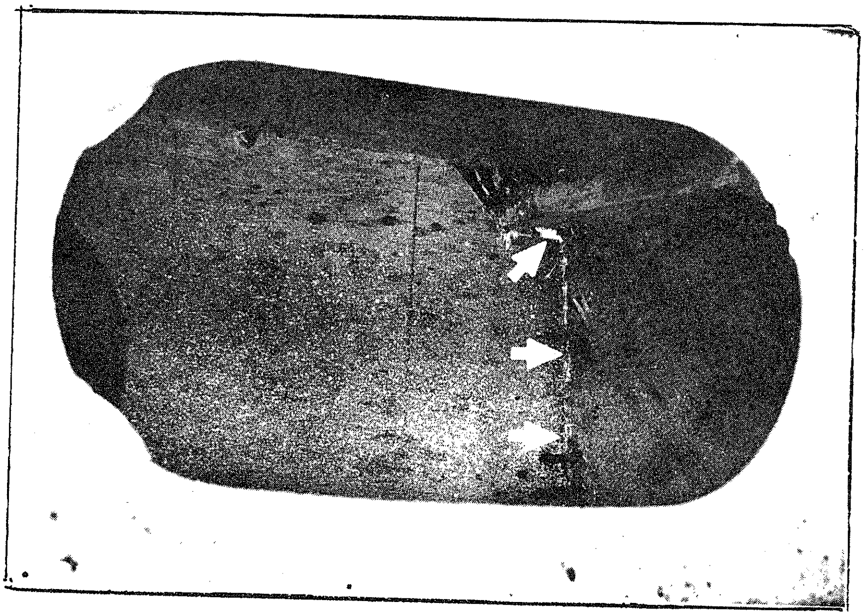

FIG. 18. SPAR/OUTBOARD GLUE FAILURE VIEWED THROUGH THE TIP RIB. GEMINI G-AJWC.